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A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE OHIO RIVER. I. THE PLANKTON AND RELATED ORGANISMS

W. C. Purdy

Public Health Service
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A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE OHIO RIVER

I. THE PLANKTON AND RELATED ORGANISMS

II. Report on surveys and laboratory studies. See FSR. 6 X 143

III Factors concerned in the phenomena of oxidation and reaeration See FSR. 6 X 146

BY

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PREFACE.

The biological studies which are here reported were made during the years 1914 and 1915 as a part of a more comprehensive study of the pollution and natural purification of the Ohio River, under the direction of Surg. W. H. Frost. The investigation comprised:

1. A sanitary survey of the watershed with special reference to the sources and extent of pollution with domestic sewage and industrial wastes, the sources and quality of municipal water supplies, and the prevalence of water-borne infectious diseases.

2. A hydrometric study, carried out with the cooperation and guidance of the United States Geological Survey, designed to give accurate information as to the discharge of the Ohio at various points, also the velocities and corresponding times of flow between consecutive points of observation.

3. A detailed study of the conditions of pollution actually existing in the river, as shown by chemical, bacteriological, and biological (plankton) examination of samples collected from fixed sampling stations at frequent intervals throughout the period of the study.

The establishment for this study consisted of an administrative office and central laboratory at Cincinnati, Ohio, with five branch laboratories in operation during the spring and summer of 1914 at selected points from Pittsburgh to the mouth of the river. The collection and examination of chemical and bacteriological samples were begun in January, 1914, but the biological survey was necessarily begun later, on August 1, 1914. From that date until October 15, 1914, biological samples were collected regularly from sampling stations in the vicinity of each of the five laboratories, thus covering the full length of the river. On October 15 observations were discontinued except upon the stretch of river from Cincinnati to Louisville. Within this zone the observations begun in August, 1914, were continued without interruption until August 1, 1915, thus extending over a full seasonal cycle.

Owing to interruption during and since the World War, the general report upon the study as a whole is not yet completed. It seems proper, however, to publish this completed section dealing with plankton studies separately and in advance of the general report, for, although the plankton studies attain their full significance only when taken in connection with other phases of the investigation, they are sufficiently distinct in material and purpose to warrant separate publication.

A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE OHIO RIVER. —I. THE PLANKTON AND RELATED ORGANISMS.

BIOLOGICAL INVESTIGATIONS.

ENVIRONMENT AS A BIOLOGICAL FACTOR.

For every form of life in water there is a kind of food, a degree of temperature, a quality or quantity of air or water, a degree of light, perhaps, which is best suited to the particular requirements of the organism. In response to such favorable environment the organism thrives. Any departure from this optimum environment retards the activity of the organism. Any radical change, such as loss of food supply, or sudden extremes of heat or cold, or exposure to a toxic substance or to the attacks of an enemy, may be utterly destructive. The environment may remain essentially the same for weeks or months, changing only with the seasons, or with some similar gradual adjustment of nature, or it may be subject to continuous changes in location, in depth, in rate of movement, in amount and quality of food available, in temperature, in amount of sunlight, and in presence of enemies or of toxic substances. A large lake represents the first of these, stability of environment, while a flowing stream is the fullest expression of a condition of instability.

The plant and animal life of a flowing stream is exposed to a continuous fluctuation of the various factors constituting the environment. Not only are these factors many and varied, but the relative potency of certain ones will vary from time to time, as the moving water encounters an endless succession of physical conformations of channel, or experiences a varying chemical condition due to the continuous transformation of matter derived from many sources, or finds itself burdened with sewage, deprived of sunlight by clouds or by turbidity, subjected to changes of temperature as the seasons progress, or hampered in movement by a covering of ice which meantime reduces its supply of oxygen. Continuous change is the charm of the moving-picture panorama presented by a flowing stream, but this same source of pleasure to the nature lover becomes the vexing instability which tries the patience of the scientific student. "Nothing," says one writer, "is so constant about the environment of the flowing stream as its inconstancy. Instability is the key word of the fluviatile environment."

If the organism have sufficient powers of locomotion, it may select a place, such as a pool or a riffle, and remain there, indifferent to the continuous movement of the water. If, however, it be very small, with insufficient power of movement to resist the flow of the water, it goes wherever the water goes, and is subject to all the changes of environment encountered by the parcel of water which constitutes its home.

It is thus that minute freely floating plant and animal life of water, collectively termed the "plankton," is subject to all the varieties of environment occasioned by the changing conditions as the water progresses toward the mouth of the river. These changing conditions are physical, chemical, and biological.

PHYSICAL FACTORS.

The physical conditions are those which have to do with geographical positions and physical characteristics of the watershed and stream channel, the turbidity and temperature of the water, and access of light.

Topography, velocity of stream movement, and character of surface soil influence turbidity and determine time of passage. Geographical relation of main and tributary streams and seasonal variation affect the temperature of the environment. Sudden and disastrous change may result to the plankton from seasonal or tributary influence.

The relation of volume of water to amount of bottom area and surface exposure, and the presence of bars, islands, bowlders, dams, shallow riffles, and deep pools affect aeration, access of light, temperature, and, it may be, freedom from a near-septic condition on the bottom.

Temperature affects many plankton organisms profoundly. Usually the advent of cold weather results in large decrease in number. However, there are certains kinds that thrive best during the cooler weather of fall or spring. Comparatively few forms flourish during the degree of cold prevalent in our northern rivers. Kofoid (1903) found that when the temperature of the Illinois River fell to 45° F. there was a decrease of over 90 per cent in the total plankton yield.

CHEMICAL FACTORS.

The chemical condition of water becomes a factor in the biological life owing to the fact that all aquatic organisms, both plant and animal, require more or less oxygen; most aquatic plants require carbon dioxide; and the simpler organisms, both plant and animal, utilize to some extent certain dissolved salts and organic substances. These beginnings of life form the connecting link between the dis-

solved materials in the water and the larger organisms which in turn prey upon the smaller forms to a great extent.

Dissolved salts and organic matter are always present, although in varying amounts, in a stream. They are derived from natural drainage of the land and from the industrial wastes and sewage of cities. The processes of decay and bacterial activity release soluble nitrogen compounds and carbon dioxide to the water. The metabolism of certain organisms results in waste products which are food for others.

BIOLOGICAL FACTORS.

There are, furthermore, numerous interrelationships existing among the organisms themselves, constituting the biological environment. These biological relationships are concerned almost entirely with the matter of food, and are therefore reducible, in the final analysis, to terms of properly related physical and chemical environment. Organisms whose life processes are holophytic (plantlike) are able to elaborate food from dissolved inorganic materials by the aid of sunlight. The plant body thus nourished, however, becomes a prey to various minute animals, some of which are in turn devoured by larger predaceous forms. Other animals are scavengers, and find most of their food in particles of suspended organic matter and in the disintegrating remains of plants or of other animals. Various "chains of food relations" (Kofoid, 1903) are thus established, some being short and simple, while others are surprisingly long and complex, interlinked with many other food chains. Most of these chains finally end in the larger forms of aquatic life, especially fish, these in turn becoming the prey of numerous waterfowl and certain water animals, such as otter, mink, etc. Man himself is to be included among the animals that find much of their food in the larger aquatic organisms, such as fish, turtles, crabs, lobsters, and bivalves.

SIGNIFICANCE OF BIOLOGICAL FINDINGS AND PURPOSES OF THE PRESENT INVESTIGATION.

If it be true that the biological life of a stream is distinctly and profoundly affected by the numerous factors which form the environment, it follows that the organisms in a stream constitute in a general way a reflection of the prevailing environmental condition of that stream. This is true at least to the extent that the presence of any particular organism in unusual abundance is evidence of the relative potency of certain factors existing in that particular environment especially favorable to such organisms. Chief among such factors is food supply.

The securing of adequate supplies of suitable food constitutes the chief activity of practically all water organisms, particularly those of microscopic size. Comparatively speaking, little time is spent in other

activities, such as mating, nest building, caring for offspring, etc., which require so large a proportion of the time and energy of larger animals, especially land forms. Microscopic life in water apparently has little else to do except to eat incessantly or assimilate continually. Reproduction by fission or by eggs usually takes place meantime, with but little cessation of the process of eating. Because of this state of affairs it becomes necessary to study with particular care the food habits of these organisms. Some of these food habits may now be briefly considered.

Plants containing chlorophyll or its equivalent require sunlight, by means of which they elaborate their food from simple substances, chiefly CO_2 and water. Thus, a week or more of clear weather is usually followed by a distinct and often remarkable increase of minute aquatic plants, unless turbidity of the water shuts out the sunlight. It will thus be seen that sunshine and turbidity of water are vitally concerned in the food supply of submerged plants.

Various organisms, such as certain rotifers, are, in part at least, herbivorous (Kofoid, 1904, p. 145), finding much of their food in these minute plants, which in turn are dependent largely on sunshine and clear water. Other organisms, notably certain crustacea, are regarded as scavengers because they consume as food the partly decayed fragments of various animal and plant forms. (Herrick, 1884, p. 124; Rafter and Baker, 1900, p. 76.) Most of the ciliates and certain of the flagellates find the greater part of their food in sewage-polluted water. They are most abundant when very large numbers of bacteria are present. Evidently some of these are bacteria eaters (Calkins, 1909, pp. 79, 106; Marsson, in Engineering News, August 31, 1911), while others probably consume suspended organic matter found in such polluted water.

Beyond the mere facts of food supply and preferred habitat, however, there is a still more important aspect of the relations of these organisms to their environment. Knowledge of foods and general activities of these various groups of organisms brings with it certain information concerning the effect of these activities upon the stream, especially in the case of a polluted stream in the course of self-purification. Briefly stated, these two biological aspects, which are distinct though intermingled, are the biological reaction to the environment of the stream and the physical and chemical reaction to the biological activities.

Sunshine and low turbidity favor the growth of diatoms and other algæ whose small size is fairly balanced by their vast numbers, and whose synthetic activity results in appreciable increase of the dissolved oxygen of the water. (Palmer, 1897.) This dissolved oxygen is not only used in the respiration of most water organisms, both plant and animal, but it is quite essential to the process of biochemi-

cal self-purification of the stream. Again, crustacea and rotifers, which find much of their food in the general detritus and suspended matter resulting from the decay of plants or other organic matter, are voracious feeders, and when present in large numbers dispose of no small amount of material in their promiscuous and continuous foraging. The organic matter thus consumed removes a considerable burden from the polluted water with corresponding improvement in its chemical and physical condition. Finally, if the water be burdened with sewage, the large amount of organic matter thus introduced is attacked by the bacteria and by hosts of larger organisms conveniently termed septic or pollutional organisms (Forbes and Richardson, 1913, pp. 498, 513) and consisting largely of ciliates and certain flagellates. These feed upon the bacteria as well as upon the organic detritus, and assist in the reduction of polluting material.

As sedimentation is often an important factor in the process of self-purification, it may be anticipated that the biological conditions existing in the bottom deposits when such deposits are present constitute an important phase of the biology of the stream.

The smaller organisms in mud, mostly animal forms, consist chiefly of worms, young mollusks, and insect larvæ and pupæ. The presence of these organisms is largely a matter of food supply, it would seem, for they are found burrowing and delving in the bottom deposits, and the fecal excretions of some of them show a large proportion of mud. F .rthermore, the mud itself shows the effects of being worked over by some of these organisms, notably the oligochæte worms. Young bivalve mollusks find their chief food supply in minute organisms in the water, rather than in the mud in which they lie partly buried. In many instances the food habits of the organisms concerned are only partially known. This is particularly true of several of the insect larvæ.

The study of bottom sediments furnishes a sort of summary or average of the conditions that have affected the water while the sediments were accumulating. In the study of the Illinois River, Forbes and Richardson (1913) found that the study of the bottom sludges and deposits was highly important and that "the silt and other deposits accumulating on the bottom of a stream are in some respects more significant of its average condition than are the waters of its current." Recent study of the Potomac River (Purdy, 1916) tends to show similar importance of the bottom sediments.

It will thus be seen that the persistent presence and abundance of certain organisms, or the absence of others, or the sudden advent of certain forms in large numbers, all have a reasonably direct significance with regard both to the environmental condition and to the biological processes of purification that are operative therein.

In order that this significance may be better defined, and hence made of more service in the study of the general problem of stream economy, biological investigations of streams, especially in direct conjunction with chemical and bacteriological investigations, are highly desirable. If the activity of high bacterial content produces appreciable differences in chemical content of polluted water, it seems very probable that the diverse activities of an abundant plankton may also produce appreciable differences. That this is the true state of affairs is indicated by results from the comparatively small amount of work already done in this country, and also by the more extensive work done in Europe, especially in Germany. Whipple (1913, p. 142) says:

> An important question, and one which is of particular interest to water analysts, is the relation between the growth of organisms (plankton) and the chemical analysis of the water in which the organisms are found. Unquestionably there must be such a relation, but thus far our knowledge of the food requirements of the plankton is not sufficient to enable us to tell what this relation is.

Much additional work must be done, however, to give this undeveloped phase of water examination the same standing as that now enjoyed by the better-known chemical and bacteriological procedures. As in the case of the other biological sciences, there is required first routine observation and classification of the phenomena exhibited, together with the associated physical and chemical facts with which these phenomena may reasonably be expected to be correlated. The search for and study of such correlations may be profitably undertaken at the same time, and to this end the various aquatic organisms, including both plankton forms and population of bottom sediments, may be classified or arranged with respect to their attitude toward sewage; that is, their liking for it, indifference toward, or avoidance of it. The recording and classification of a considerable amount of observational material is a prerequisite, however, to any comprehensive generalization.

Many biologists have undertaken such a classification, regarding the organisms as "living reagents" (Kolkwitz, 1911) which react in a definite manner toward sewage or similar pollution.

Whipple (1913) showed that, in the Genesee River, the heavily polluted portion just below the Rochester sewer outfalls furnished very high numbers of bacteria and of certain ciliates and other protozoa. Some miles farther downstream, where chemical and bacteriological evidences of pollution were less apparent, these ciliates diminished greatly in numbers, and certain algæ appeared, these organisms to be followed, some miles below, by rotifers as the dominating organism, and finally by crustacea, as the water became progressively better in quality.

In an elaborate five-year study of the Illinois River for the threefold purpose of determining the biological population, studying the life histories and mutual dependencies of these organisms, and, finally, studying and analyzing the factors of environment, Kofoid (1903, 1904) made a notable contribution to our knowledge of plankton activities. Very briefly summarized, his more important findings are as follows:

1. The age of the water is a vital factor in production of plankton, a long time-factor permitting adequate decomposition of the contained organic matter, which in turn provided sufficient food, directly or indirectly, for the aquatic population. Conversely, a short time-factor is unfavorable to plankton growth.

2. There is little correlation between seasonal flux in chemical conditions (as shown by analyses) and seasonal course of plankton production. Nitrogenous matters are influenced, especially by rapid growth of diatoms, but changes are not uniform nor proportional.

3. Temperature affects plankton profoundly. It was noted that when temperature was below 45° F. (= 7° C.) the plankton content of the river channel was only 9 per cent of that present when temperatures were higher.

4. Diatoms are frequently very abundant and are of great importance and significance in the food supply of higher organisms. Abundance of other minute organisms containing chlorophyll provides food for large numbers of rotifers.

5. Aquatic insects are important by reason of many food relations connecting them with the smaller plankton organisms.

6. The presence of considerable amounts of organic matter, such as sewage, apparently initiates a well-defined series of biological events, beginning with high bacterial content and large numbers of ciliates. Minute chlorophyll-bearing organisms, both algæ and certain of the Mastigophora, then appear, to be followed usually by larger organisms (rotifers, rhizopods, and crustacea), which find most of their food in the more minute animals and plants.

7. Certain ciliates are very abundant during the height of sewage contamination and bacterial development. They are unusually important in the economy of the plankton, as they feed chiefly on bacteria, decaying organic matter, and the smaller algæ and are themselves eaten by rotifers. These ciliates are active agents in the reduction of sewage, in destruction of the bacteria of decay, and in purification of sewage-laden waters, transferring the matter therein to higher forms of animal life.

8. Plankton production is essentially rhythmic or periodic, the waves or "pulses" being from three to five weeks in duration. Amplitude of pulses is affected by local influences and by season.

Rising temperature, hydrographic stability, decaying vegetation, or access to sewage tend to increase plankton, while declining temperatures, dilution of fertilizing material, access of flood waters, and increase of current all tend to decrease plankton. Initial causes for plankton pulses are traceable through complex food relations which extend from the larger animal forms back to the minute algæ and other synthetic organisms. These in turn are dependent on sunlight and on dissolved matter in the water. Another line is traceable from certain ciliates and flagellates back through the bacteria, which owe their chief food to the contamination, usually sewage, which causes the high bacterial growth.

While the stated objects of Kofoid's investigation made no reference to any particular factor of environment, it is significant that, in a research thus disinterested, there should be frequent allusion to the evident effect of sewage contamination as expressed by the presence of large numbers of certain Mastigophora and ciliates.

Kofoid's work was completed before the opening of the Chicago Sanitary Canal, in 1900, poured a large volume of sewage into the Illinois River. It is therefore fortunate that a further investigation of this stream (Biology of the Upper Illinois, Forbes and Richardson, 1913) gives for comparison the biological conditions which prevailed after the addition of Chicago's sewage. A second object of this later study was "a description of the criteria and effects of different degrees of contamination of the natural waters of the Illinois." (Idem p. 498.) A brief summary of results is here appended:

The average amount of plankton after the opening of the canal was 5.07 c. c. per cubic meter of water, as compared with 3 c. c. per cubic meter previous to the opening. This average increase of 69 per cent was traceable to favorable plankton environment resulting when the largely increased volume of water overspread fertile bottom lands, and sewage from Chicago provided further large amounts of organic matter as food for microscopic organisms.

In correlating distinguishable stages of pollution with their respective chemical and biological characteristics, the river was divided into four sections, in the order of diminishing impurity, and designated by the terms "septic," "polluted," "contaminated," and, finally, "clean water." Analogous terms were applied to the characteristic organisms found in the respective waters. The following is a summary of the chief findings in these four zones of pollution:

Section 1.—Sanitary Canal at Lockport and Des Plaines River at Lockport. (This is about 33 miles below the source of the Sanitary Canal, which, after a flow of 38 miles, empties into the Des Plaines River at Joliet, Ill.)

Character.—Septic.

General and chemical conditions.—In canal, water clear. Offal, human excrement, and general refuse stranded or floating, but little decayed. Noticeable sewage odor. Sludge with foul odor. Dissolved oxygen averaged about 31.9 per cent of saturation. In Des Plaines River, water grayish. Decomposition well advanced. Foul privy odor. Conditions less offensive during cooler weather.

Biological content.—In canal, an occasional living fish. Many dead ones, floating or stranded alongshore. (Fish were a common Lake Michigan species.) No animal life in bottom sludges. Scattered algæ along edges of canal harbored the septic rotifer *R. actinurus* and the protozoa *Bodo*, *Vorticella*, *Oikomonas*, and *Anthophysa*, also septic. In Des Plaines River, bottom stones covered with sewage fungus (*Sphærotilus*) and blue-green algæ. *Anthophysa*, *Carchesium*, *Paramæcium*, and other septic protozoa abundant. Various less septic forms present. No fish in September, a few in November, but in dying condition. Many oligochæte and nematode worms in sludge. No mollusks or crustacea.

Section 2.—Des Plaines River at Dresden Heights (16 miles below mouth of the Sanitary Canal) and Illinois River from this point to Marseilles, a distance of 26 miles.

Character.—Polluted.

General and chemical conditions.—In Des Plaines River, water grayish, with privy odor. Dissolved oxygen averaged 13.1 per cent of saturation. In Illinois River, water grayish and clouded with tufts of sewage fungus (*Sphærotilus*). Masses of putrescent material floating on warmest days. Gas bubbles from bottom. Foul odor from both water and sludge. Dissolved oxygen ranged from 3.1 to 16.4 per cent of saturation. Unpolluted Kankakee (tributary) showed dissolved oxygen content of 108 to 127 per cent of saturation.

Biological content.—In Des Plaines River, large amounts of *Sphærotilus* and *Carchesium*. The blue-green algæ *Oscillatoria* and *Phormidium* were frequent. Other algæ present during cooler weather. No fish; no vertebrates except one frog. Many dead mollusks. Air-breathing beetles common. No sponges, hydroids, leeches, planarians, or crustaceans. In Illinois River, *Sphærotilus*, *Carchesium*, and *Vorticella* abundant. *Colpidium* and *Rotifer actinurus* present. Fish absent except an occasional specimen. Fungi and *Oscillatoria* in sludge; also immense numbers of worms (*Tubifex*). No mollusks, crayfish, or larvæ of May fly or Dragon fly. Conditions a little better in cooler weather.

Section 3.—Illinois River from Marseilles (42 miles below mouth of Sanitary Canal) to Starved Rock, a stretch of 16 miles.

Character.—Contaminated.

General and chemical conditions.—Water grayish. Disagreeable odor. No gas bubbles. Dissolved oxygen about 16 per cent of sat-

uration. Advent of Fox River (relatively pure) and passage of main stream over dam help to improve conditions at Starved Rock, where dissolved oxygen averages 43.6 per cent of saturation near north shore (due to Fox River) and 35.9 per cent near south shore.

Biological content.—*Sphærotilus*, *Carchesium*, *Epistylis*, and other septic organisms very few. At Starved Rock the only sewage organism found is small amounts of *Sphærotilus*. Fish in small numbers along edge of river, farther downstream are found in some variety in mid-channel, and at Starved Rock are moderately abundant. Blue-green algæ (pollutional) fairly common near Marseilles, but scarce at Starved Rock, green algæ increasing meantime. Some worms (*Tubifex*) in bottom mud. Insect larvæ, snails, crawfish, leeches, etc., more numerous.

Section 4.—Illinois River from Starved Rock (58 miles below mouth of Sanitary Canal) to Chillicothe, 107 miles below the canal. This section is 49 miles long.

Character.—Relatively pure water.

General and chemical conditions.—Water very slightly grayish, nearly normal; becomes greenish toward Chillicothe, and the slight odor of sewage disappears. Only in winter do bottom sludges show offensive odor. Dissolved oxygen 22 to 28 per cent of saturation in midsummer, reaching maximum of 82 per cent in November.

Biological content.—Septic and pollutional organisms only occasional or absent. Fish numerous enough to justify commercial fishing. Green algæ predominate, the blue-greens being only occasional. Water is made green by large amount of minute chlorophyll-bearing plankton. Large variety of insect larvæ and of mussels, snails, and crustacea. Sponges, leeches, bryozoa, and planarians are fairly common. *Tubifex* is rare in bottom sediments.

This investigation thus indicates that a water burdened with sewage and "sick" according to all available evidence has meantime a characteristic biological content which is totally different from that shown in the lowest section studied, at which time the physical and chemical conditions also indicate that self-purification is far advanced. The recovering water is now 107 miles below the mouth of the Sanitary Canal, and it still has 180 miles to flow before it reaches the Mississippi River.

A considerable amount of work has been done by European investigators, especially in Germany. Kolkwitz (1911), in studying the organisms and conditions resulting from sewage pollution, divides the water into three zones—the sewage zone, with polysaprobic organisms, and transition zone, with mesosaprobic organisms, and the clean water zone, with oligosaprobic organisms. These terms have essentially the same significance as "septic," "polluted," "contaminated,"

and "clean water," as used by Forbes and Richardson (1913). This will be evident from the following further explanation by Kolkwitz, essentially as translated by Kuichling:

Polysaprobic zone.—Characterized by multitude of Schizomycetes (bacteria), bacteria-eating Flagellata and Ciliata. * * * From a chemical standpoint this zone is also marked by the predominance of reducing and splitting processes due to lack of dissolved oxygen and to the excess of carbonic acid; also to relatively high content of decomposable food matters, which is indicated by the growth of certain organisms that may be regarded as living reagents.

Mesosaprobic zone.—The process of decomposition has advanced to an intermediate degree. For convenience this zone will be divided into two parts, called A-mesosaprobic, and B-mesosaprobic, the first extending upstream and adjoining the polysaprobic zone, and the second extending down stream and adjoining the clean-water or oligosaprobic zone. The first part is usually characterized by the appearance of Schizophyceæ and Eumycetes, along with *Anthophysa vegetans, Stentor cœru'eus, Carchesium lachmanni*, etc. Many bacteria are still present. Drainage ditches carrying imperfectly purified water are good examples of A-mesosaprobic zones. The B-mesosaprobic zone is generally distinguished by its contents of Diatomaceæ and certain Chlorophyceæ, along with Rhizopoda, certain Ciliata, Vermes, numerous Rotatoria, etc.

Oligosaprobic zone.—Hygienic interest in the disposal of sewage generally terminates at this zone, while it begins herewith in the case of domestic water supplies. The chief characteristic of this zone is the completion of the process of mineralization; all of the more or less turbulent processes of self-purification are absent in the water itself, and the biological development is usually extensive. The appearance of certain representatives of the Peridiniales, all Charales, and certain planktonal Ciliata, Rotatoria, and Crustacea are to be regarded as characteristic.

Marsson (1911), of the royal Prussian testing station, studied the significance of plankton in maintaining purity of natural waters and the effect of sewage on these organisms. He says of the plankton:

Its vegetable component is the fundamental food supply or condition of existence for all aquatic life. It comes from the products of the decomposition of * * * decaying animals and plants as well as from sewage. The self-purifying power of natural waters is merely the maintenance of the proper equilibrium between retrogressive and progressive metamorphosis. * * *

After designating as "Food producers" those plantlike organisms which assimilate inorganic matter and, aided by sunlight, build up organic compounds by means of chlorophyll, and further classifying as "Food consumers" all remaining organisms (chiefly animals), Marsson notes the great importance of the activity of algæ in stream economy, and remarks, concerning certain flagellates:

The euglenas and their relatives are therefore found mainly in nauseous pools whose surface they cover with a green scum. They appear on every sewage farm and especially on the surface of sewage held in tanks. They also develop in great numbers in sluggish indentations of the banks of polluted streams, from which they are carried along by the current. When found plentifully in the plankton, they afford proof that the water has been contaminated.

In discussing "Food consumers" Marsson speaks of the consumption of bacteria by larger organisms, chiefly ciliates, and says:

> These relatively large unicellular organisms thus dominate over the other living organisms in their vicinity, according to their size, like a cannibal among fish. Many of the metazoa, including the Rotatoria, are likewise bacteria eaters and obtain their food in the same manner as the ciliates. Besides bacteria, this food material embraces other bacteria eaters, diatoms, small algæ, etc. If many bacteria eaters are found in a water, it can safely be inferred that many bacteria are present, hence also a quantity of putrefying substances. * * *

Referring to the effect on plankton of organic matter such as sewage, he says:

> It may also be said that the greater the quantity of impurities reaching a stream, the stronger will be the development of the plankton and the greater the amount of work it will have to perform by means of its nutrition and growth.

Eyferth (1900) describes many hundreds of aquatic organisms, both plants and animals, and ranging from bacteria to rotifers. He gives particular attention to the conditions of environment as shown by the preferred habitat of the various organisms, and, as far as known facts permit, states the attitude of each organism toward pollution, using the terms polysaprobic, mesosaprobic, and oligosaprobic, as suggested by Kolkwitz. Senft (1905) similarly regards many of the aquatic organisms as "living reagents" on account of their observed behavior toward pollution, and classifies them accordingly, using the terms of Kolkwitz.

Various other workers, both American and European, have commented on the observed behavior of aquatic organisms toward organic matter, and have regarded this microscopic life as a factor in the self-purification of surface waters. It seems probable that in the study of aquatic organisms we have a source of evidence relative to the true mechanism of self-purification of streams which is sufficiently important to command a respectful hearing along with the better-known evidence obtained meantime from bacteriological study and chemical examination. Referring to the advantage of maintaining a normal distribution of plant and animal life in a polluted stream to the end that organic matter in water may be most effectively disposed of, Whipple (1914, p. 82) says:

> The author believes that ultimately the great question of the permissible limit of stream pollution will be solved on this basis.

In view of all these facts it seemed highly desirable that the investigations of the pollution and self-purification of the Ohio River should include certain biological studies. The purpose of these studies may be said to have been twofold. There was first the general purpose of recording and classifying the available data as a contribution to the biology of streams in general. It was hoped that in addition an intensive study of the biology of the Ohio might

furnish some information of immediate importance in the interpretation of the physical, chemical, and bacteriological data that it was proposed to assemble. This branch of the investigation was therefore organized with these two purposes in view.

METHODS EMPLOYED.

PLANKTON.

Purpose, scope, and plan of the biological work.—Recognition of the fact, often noted, that a sewage-polluted stream gradually becomes purified by natural means logically implies that the proper study of such a stream must include a careful survey of all known agents of nature which may be concerned in the purification process. With this end in view it was arranged to study the microscopic plants and animals and the related organisms predominating in the various portions of the river in order that additional data might be secured to consider in connection with the chemical and bacteriological data that were being secured meantime by a study of the same portions of the river.

Laboratories were established at six selected points along the river, as follows: (1) At Pittsburgh, where the Ohio River is formed by the confluence of the Allegheny and the Monongahela Rivers; (2) at Wheeling, 97 miles below Pittsburgh; (3) at Portsmouth, 355 miles below; (4) at Cincinnati, 480 miles; (5) at Louisville, 620 miles; and (6) at Paducah, 920 miles, respectively, down stream from Pittsburgh. The Paducah laboratory was within 47 miles of the Mississippi River, into which the Ohio River flows.

At each of these six cities several sampling stations were established in order to obtain representative samples of the water: (1) Above the city and untouched by local pollution; (2) below the city, and presumably showing the effects of any sewage, industrial waste, etc., introduced locally. Thus, at Pittsburgh, the several biological sampling points were located: (1) 12 miles up the Monongahela from the confluence at Pittsburgh, (2) 7 miles up the Allegheny, (3) 3 miles below the confluence at Pittsburgh, (4) 23 miles below the confluence. This last point also had reference to the condition of the Ohio water before the advent of the Beaver River, which entered at about 25 miles below Pittsburgh. Samples of this tributary were taken well up above the mouth to determine the biological status of this stream. Various other Ohio tributaries, regarded as important on account of their probable sanitary status or their effect as a dilution factor, were sampled in like manner.

Plankton samples were taken weekly as a rule. Bottom sediments were sampled less often—twice a month, or in some cases once a month. The time period covered was August 1 to October 15, 1914, in

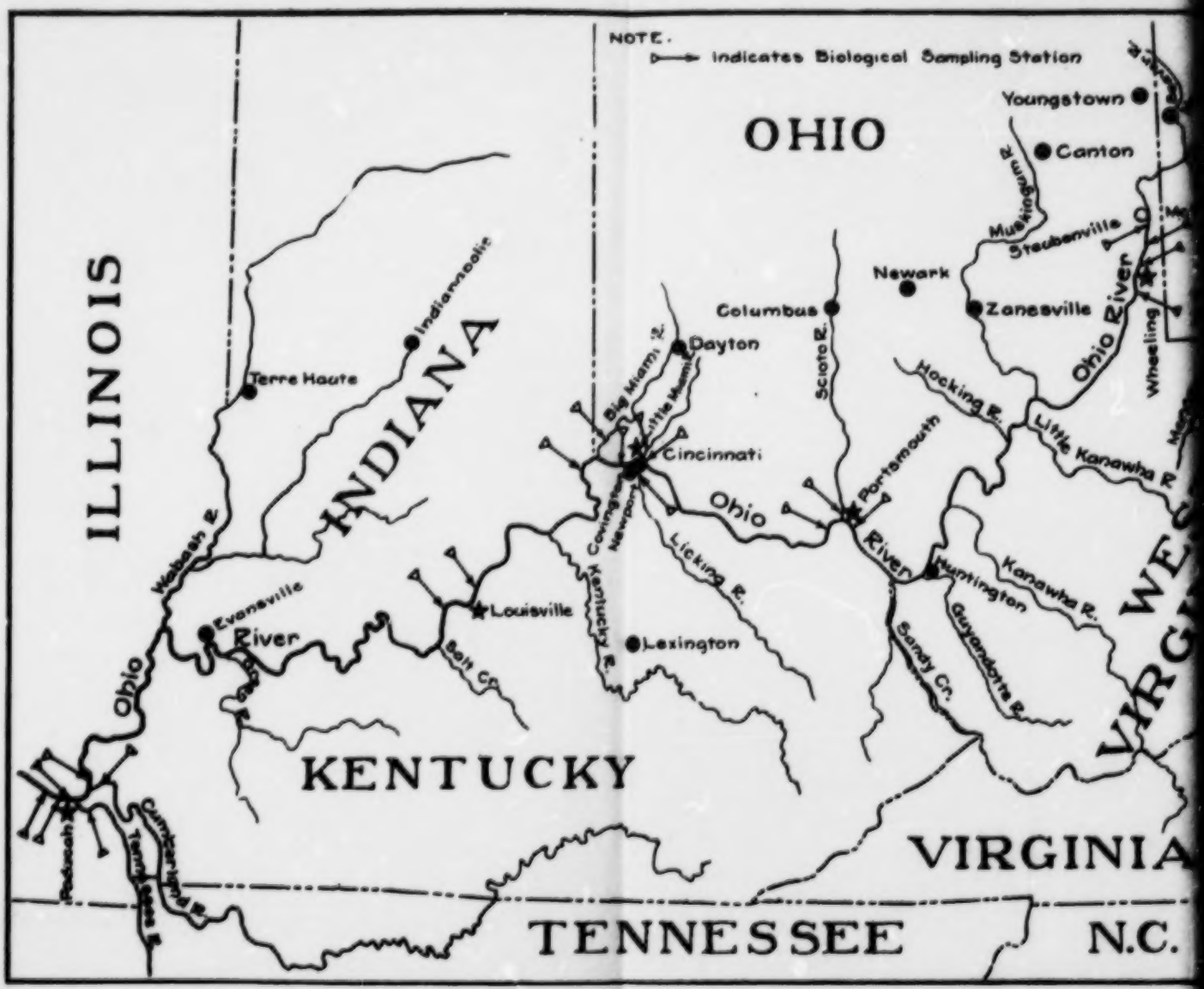
all stations except those near Cincinnati, where some intensive work was continued until August, 1915.

Table No. 1, given herewith, lists the 6 successive laboratories, 26 collecting stations, time periods covered, frequency of collection, and kinds of samples secured in the effort to secure an adequate and impartial biological picture of the Ohio River. These sampling points are designated on the map of the Ohio River District also.

TABLE NO. 1.—*Record of biological samples.*

Station.	Sampling point (miles from Pittsburgh).	Time included by samples collected.	Number of samples and frequency of collection.			
			Plankton (weekly).	Mud (semi-monthly).	Miscellaneous (occasional).	Total.
Pittsburgh	M-12	Aug. 12 to Oct. 15, 1914.	10	5	1	16
	A-7	do	10	7	1	18
	O-3	do	10	7	1	18
	O-23	do	10			10
	Beaver River	do	10	5	1	16
Total			50	24	4	78
Wheeling	65	Aug. 14 to Oct. 15, 1914.	9			9
	77	do	8			8
	88	do	[1] 4			4
	97 or dam No. 13	do	10			10
Total			31			31
Portsmouth	349	Aug. 18 to Oct. 15, 1914.	7	4	1	12
	Scioto River	do	7	3		10
	358	do	7	4		11
Total			21	11	1	33
Cincinnati	461	July 22, 1914, to Aug. 1, 1915.	46	10		56
	475	do	50	[2] 84		134
	492	Sept. 16, 1914, to Aug. 1, 1915.	49	[3] 49		98
	Little Miami River	Sept. 16, 1914, to May 26, 1915.	33	1		34
	Licking River	July 22, 1914, to June 1, 1915.	36	9	1	46
	Great Miami River	Sept. 16, 1914, to Aug. 1, 1915.	39	2	1	42
Total			253	155	2	410
Louisville	598	Aug. 31, 1914, to Aug. 1, 1915.	49	[2] 97	10	156
	619, N and C	Aug. 31, 1914, to May 1, 1915.	35	34		69
	619-S	do	36	1		37
Total			120	122	10	252
Paducah	904	Sept. 2 to Oct. 12, 1914.	5	3		8
	Cumberland River	do	4	4		8
	920, N and C	do	5	3		8
	920-S	do	4			4
	Tennessee River	do	6	5		11
	936-S	do	4	6		10
	963, N and C	do	5			5
	963-S	do	5			5
Total			38	21		59
Grand total			513	333	17	863

[1] Biweekly. [2] To November, 1915. [3] To December, 1915.


NOTE.
Indicates Biological Sampling Station
OHIO
ILLINOIS
INDIANA
KENTUCKY
VIRGINIA
TENNESSEE
N.C.
Youngstown
Canton
Steubenville
Newark
Columbus
Zanesville
Dayton
Terre Haute
Indianapolis
Cincinnati
Portsmouth
Louisville
Lexington
Huntington
Evansville
Paducah
Ohio River
Wheeling
Muskingum R.
Scioto R.
Big Miami R.
Little Miami R.
Hocking R.
Little Kanawha R.
Licking R.
Kentucky R.
Kanawha R.
Guyandotte R.
Sandy Cr.
Salt Cr.
Wabash R.
Cumberland R.
Tennessee R.

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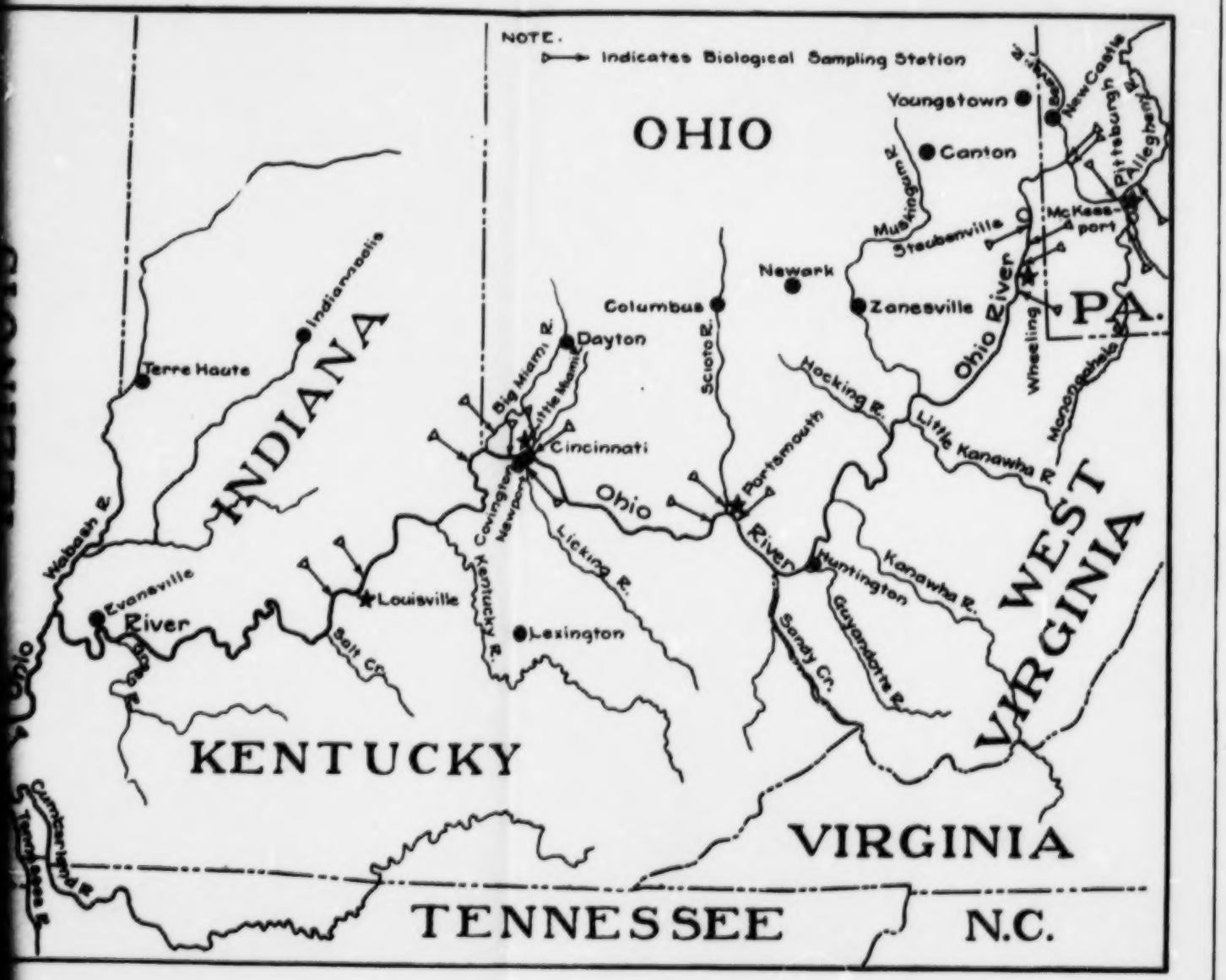

15077—28. (Face p. 14.)

B

Plankton samples collected at the five branch laboratories were concentrated by use of the Sedgwick-Rafter filter, the resulting catch preserved by adding alcohol, and then shipped to headquarters at Cincinnati for examination. Samples of bottom sediment were preserved by alcohol and shipped to the Cincinnati laboratory for study.

Sampling.—Water samples for Plankton determination were secured by using the Dissolved Oxygen Sampler. This was a cylindrical vessel of about 3 liters capacity and constructed of copper. The air-tight, removable lid was provided with three small tubes, which extended within the vessel, permitting outflow of air and inflow of water. This sampler was lowered nearly to the bottom of the stream, then raised slowly as the water entered, displacing the air. In this manner a "vertical" sample was obtained which was made up of water from bottom to surface of the stream. In most cases, unless the stream was narrow at the sampling point, this procedure was carried out at the three points on a cross section of the channel. The final plankton sample of 2 liters was composited from the water thus obtained. Conditions of weather, stream movement, floating débris, and presence of fish and submerged plants were noted. At the laboratory these data were entered on a field card for convenient reference.

At the laboratory the 2-liter sample was concentrated by filtering through a Sedgwick-Rafter funnel, the catch preserved by the addition of strong alcohol, and labeled with name or number of the sampling station, date, amount of water filtered, and degree of concentration. Later, when the catch was measured by centrifuging, the amount of catch was also recorded on the label.

Examination.—One cubic centimeter of the catch, diluted if necessary, was placed in a Sedgwick-Rafter cell and examined with a binocular microscope magnifying 23 diameters. This was merely a rapid survey of the entire slide in order to note the chief features of the material to be studied, the uniformity of distribution over the slide, and the approximate number and kind of the larger organisms.

Further study was carried on by the aid of a Zeiss microscope with two-thirds objective and No. 4 ocular, giving a magnification of about 60 diameters. The count is made by means of a micrometer eyepiece according to the method given by Whipple (1914), 10 fields uniformly distributed over the slide being examined and the results tabulated.

Identification of organisms.—The organisms comprise eight general divisions, as follows: Diatomaceæ, Algæ, Fungi, Rhizopoda, Mastigophora (or Flagellates), Ciliata, Rotifera, and Crustacea. To these is added a division to include the various minute worms, eggs, spores, or other unclassified organisms that occasionally appear in the plankton. Each of these main divisions consists of several groups, and these are, in turn, divided into other groups or families, with further division into genera and finally species.

Identification has been facilitated by reference to the following: Whipple (1914), Conn (1905) (1908), Miall (1912), Hudson and Gosse (1889), Wolle (1887) (1892) (1894), Leidy (1879), Collins (1909), Tilden (1910), Snow 1903), Eyferth (1909), Senft (1905).

Another helpful means of identifying organisms is by the use of a set of microscope slides on which are mounted for future reference the various organisms as they are encountered in the examination of catches. An organism is removed by a capillary pipette from the counting cell, placed in a few drops of dilute formalin solution in a ringed slide, the cover slip adjusted and sealed down, and the label affixed—the whole process requiring perhaps 20 minutes.

Expression of results.—Results were recorded in terms of "standard units" (a square 20 microns on a side) inasmuch as this method serves to reduce all values to a common basis, and thus shows within certain limitations the approximate relative values of organisms of various sizes and of the amorphous matter and silt as well.

The "standard unit" (Whipple, 1914) is a unit of area and makes no allowance for the thickness of the object. In order to obtain desirable volumetric data, Whipple's recommendation that the standard unit be modified somewhat in practice in case of organisms that vary a great deal in thickness has been adopted. Accordingly, the results of plankton determinations are expressed in terms of standard units which have a constant thickness of about 20 microns, or, in other words, a volume which approximates a cubic standard unit. This is practically the application of a microscopic "board foot," or rather board inch, to the measurement of plankton, and, like board measure, it is essentially volumetric. While such measurement of microscopic objects is not exact, it nevertheless is very much nearer the true values than is obtained if no consideration whatever be given the widely fluctuating dimensions that occur.

In actual practice, the approximate shapes of the various plankton organisms to be measured may be listed as: (1) Globular bodies, (2) cylinders and cones, (3) quadrangular bodies, (4) combinations and irregulars.

Class (1) includes all spheres and near spheres, such as *Volvox*, *Chlamydomonas*, *Vorticella* (heads), and many of the ciliates.

Class (2) includes certain of the diatoms, sections of alga filaments, and some flagellates. Such organisms as *Euglena*, *Cyclops*, portions of certain rotifers and worms, etc., are essentially conical in shape and may be measured accordingly. The desmid *Closterium*, for instance, is practically a double cone.

Class (3) will include such diatoms as *Navicula*, *Synedra biceps*, etc., and a few algæ such as *Scenedesmus*.

Class (4) includes a variety of organisms, a few of which may be mentioned as typical:

Paramæcium is essentially a cylinder, capped with a half sphere at each end.

Codonella is a sphere attached to a short cylinder.

Cyclops is essentially a cone, with one end rounded into a half sphere.

Synedra is a double wedge.

Rotifers are various combinations of the sphere, the cylinder, and the cone.

Many spherical organisms are very minute. *Pleurococcus* cells may be only 10 or 12 microns in diameter. Eight or more such cells will be required to form 1 cubic standard unit.

In practice, a table similar to that illustrated herewith is a great convenience and timesaver. Such a table, copied from an Engineer's Handbook, may be posted near the workbench and consulted as the count proceeds.

TABLE GIVING AREA OF CIRCLE AND VOLUME OF SPHERE AND OF CUBE FOR A GIVEN DIAMETER.

Diameter.	Area of circle.	Volume of sphere.	Volume of cube.
0.5	0.196	0.065	0.125
1.0	.7854	.5236	1
2.0	3.1416	4.185	8
3.0	7.068	14.15	27
4.0	12.566	33.42	64
5.0	19.635	65.4	125
Etc., up to 30 or 40.			

One or two specific examples will make clear the use of the above table:

(1) Suppose a *Volvox* sphere be found, measuring 22 linear standard units in diameter. A glance at the complete table shows that such an organism has a volume of 5,575 cubic standard units.

(2) A tiny section of alga (cylindrical), one-half standard unit in diameter and 15 standard units long, has a volume of about 3 cubic standard units; that is, area of end (0.196) multiplied by length (15) equals 2.9.

(3) A flagellate (the cone-shaped *Euglena*, for example) whose larger end has a diameter of 2 standard units (linear) with a total length of 6 standard units has a volume of about 6 cubic standard units. (Area of end multiplied by one-third the length.)

(4) A cyclops, whose general shape is that of a cone with rounded base, measures, say, 12 standard units (linear) in diameter at the point where the body begins to round off to form the "head end." From this point to the tip of the tail is, say, 22 standard units in length. The volume is therefore found by multiplying the area of the base by one-third the length, or $113 \times 7\frac{1}{3} = 829$. Add to this the volume of the head end (one-half a sphere whose diameter is 12 linear

standard units) and we have 829 + 452 = 1,281 cubic standard units as the approximate volume. If egg sacs are present they may be measured separately.

By using the ocular micrometer disk devised by Whipple, the approximate volume of all plankton organisms may, with a reasonable amount of labor, be ascertained and recorded on the plankton-counting sheet, thus placing all forms, large and small, on the same volumetric basis and thereby giving an adequate representation of the relative quantitative importance of the various organisms present.

The amorphous matter and silt on the bottom of counting cell is measured in a similar manner. This material, if abundant, usually forms a partial layer of fairly uniform thickness, so the volume may be easily found by multiplying area by thickness on a given field and subtracting the total volume of plankton organisms already counted and measured in this same field. If there be but little of the amorphous matter, the discrete particles and masses in any given field may be measured as were the plankton organisms.

The errors of measurement by the foregoing procedure tend to be so related that if both organisms and amorphous matter or silt be determined by this procedure the relation between the two may be taken as approximately correct. The total volume of the catch is capable of much more accurate determination by means of the centrifuge and actual volumetric measurement, so that by applying to this volumetric measure the relative volume of plankton as determined by the count method a fair estimate of the total volume of the plankton in the catch is obtainable. This is the procedure that has been followed throughout.

Procedure with high turbidity.—Very often the turbidity is so high that it is practically impossible to filter the sample on account of the clogging of the filter by suspended matter and silt. Under such conditions it has been our practice to allow the sample to stand for a few hours, then carefully to siphon off and filter the supernatant water in the usual manner. The heavier suspended matter, which has settled to the bottom, is diluted by the addition of a measured quantity of distilled water. This is now essentially a second catch from the 2-liter sample which has just been filtered. One cubic centimeter, further diluted if necessary, is examined in the usual way in the counting cell and the results tabulated, and later added to the count of the catch obtained by filtering, after first placing both counts on a common basis. Later the settled sediments are measured and the result, reduced to like terms, is added to the quantitative data obtained by centrifuging the other portion of the catch. This material which settled to the bottom of the bottle contained, as a rule, very few organisms.

BOTTOM SEDIMENTS.

Samples.—Samples are secured by the use of a mushroom-shaped scoop dragged on the bottom of the stream by an attached rope. From the liter or two of mud thus obtained the collector takes a representative sample of about 200 c. c., which is placed in a 500 c. c. bottle and taken to the laboratory for examination. In the case of distant stations, the sample is preserved by the addition of an equal volume of strong alcohol, then shipped to the laboratory. The collector makes note of the color, the odor, and the time and place of sampling.

Examination.—The laboratory examination of these samples consists in noting the color, the odor, and the consistency or "streak." Following this, the mud is carefully washed through a fine-mesh sieve. This is accomplished by placing the mud in some such vessel as a "moist chamber"—which has perpendicular sides—running tap water into it and agitating and rotating the vessel until the water is very turbid with mud in suspension. This is then poured through the sieve. More tap water is then added, and the process repeated as often as necessary until all the mud has been passed through the sieve, whose fine meshes retain the larger organisms present (worms, insect larvæ, mollusks, etc.) and the various kinds of disintegrating organic material, chiefly fragments of leaves, plants, seeds, small sticks, molts of water animals, etc. This is essentially a process of filtration and the "catch" in the sieve is transferred to a vessel of clean water for convenient study. Results are tabulated under appropriate headings. No quantitative estimates are attempted aside from using a sample of constant size (200 c. c.). Organisms present are merely counted. Disintegrating organic material is recorded as to predominating kinds and relative abundance.

TABLE NO. 2.—*Summary of examination of bottom deposits.*

Station.	Time included by samples.	Samples, 200 c. c.				No organisms present: samples rated by physical condition only.			Samples rated by organisms.									Samples classified by the number (expressed in per cent), which show various degrees of pollution.							
			Composition.						Pollutional organisms.			Indifferent or doubtful.			Clean-water organisms.			Physical condition: Polluted. Pollutional organisms: Abundant.		Physical condition: Doubtful. Pollutional organisms: Moderate number or few. Doubtful organisms: Abundant.		Physical condition: Doubtful. Doubtful organisms: Moderate number or few.		Physical condition: Clean. Clean-water organisms: Present.	
		Number collected.	Mud.	Sand.	Gravel and pebbles.	Polluted.	Doubtful.	Clean.	Abundant.	Moderate number.	Few.	Abundant.	Moderate number.	Few.	Abundant.	Moderate number.	Few.	Pollution abundant.		Moderate amount of pollution.		Pollution slight or doubtful.		Pollution absent.	
																		(A)	(B)	(A)	(B	(A)	(B)	(A)	(B)
M-12	August to Oct. 15, 1914	4	4			2	1		1									75		25					
A-7	do	6	5		1			1	3	1	1							60		40					
O-3	do	7	5	2			2		5									100							
O-23	No mud found																								
Beaver River	August to Oct. 15, 1914	5	5				1		2		1							40		20		40			
Wheeling district	No mud found																								
340	August to Oct. 15, 1914	4	4				1			2	1									100					
Scioto River	do	3	3							2	1									100					
358	do	4	4				1				3									100					
461	July 20 to Nov. 20, 1914	10	9	1			1	3			2		4							100					
Licking River	July 20 to Nov. 5, 1914	9	7	1	1			3	3	2	1							50	45	40	22	20	55	40	22
475	July, 1914, to November, 1915	84	61	15	8		1	22	51	4	3	1	1	1				94	84	33	43			17	14
492	September, 1914, to December, 1915.	49	3	44	2			46	1	1	1							50	33	6	16				
498	do	87	69	14	4		1	19	17	14	25	4	2	4		1		10	25	50	67				
619	September, 1914, to Apr. 30, 1915.	35	4 Tr.	30	1			30	3			1						67	75	80	62	10	9		4
904	Sept. to Oct. 15, 1914	6	4	2				3		1	1									33	25				
Cumberland River	do	4	4								1		2	1						50		25		25	
920	do	2	2											2						50		50			
Tennessee River	do	5	5											2								100			
933	do	5	5				1			1	1		1	2						40		60			
												1	1	2						20		80			

NOTE.—Figures in column (A) refer to samples collected at all stations during August, September, and October, 1914. Figures in column (B) include the additional samples taken in Cincinnati-Louisville interval. Samples consisting of sand or gravel are not included in per cent calculations given.

RESULTS OF BIOLOGICAL INVESTIGATIONS.

In presenting the result of the biological studies of certain portions of the Ohio and its tributaries it is deemed advisable to set down in the same place a summary of those physical, chemical, and biological characteristics of the stream that may be supposed to determine or be influenced by the presence of the microscopic plant and animal life under investigation.

These various characteristics have been studied in detail and are described more fully in the separate report upon hydrometric, chemical, and bacteriological studies of the river. An effort to summarize the essential factors, giving to each its due weight, and thus to arrive at some reasonable conclusions as to the general biological situation at any given station, is a task attended by perplexing problems and real difficulties. Aquatic life responds to changes in its environment. If this environment be made up of many and diverse factors, the resulting biological situation is correspondingly complex. As stated by Kofoid (1904, p. 41), the organisms in a stream constitute "the biological expression of the state of tension among these various factors which for the moment exists," the factors referred to being a most complex series "whose number and relative potency are subject to constant change and readjustment in the unstable environment of the stream."

It will not be attempted, therefore, to analyze the environmental conditions in terms of biological activity, but rather to set down side by side a summary of the river characteristics and of the biological findings at each station in order that the way may be partially prepared for a study of whatever correlations may exist between the two. That such correlations do exist may be anticipated from general biological principles; and certain marked tendencies are plainly apparent in the data that will be presented in the following pages. It is only by the painstaking collecting, recording, and analyzing of a large amount of observational data of this sort that it will be possible to arrive at a state of knowledge of the ecology of microscopic life comparable with the similar knowledge which now exists in the case of the better-known higher plants and animals.

THE OHIO RIVER.

The Ohio River, formed in southwestern Pennsylvania by the confluence of the Allegheny and Monongahela Rivers, flows in a general southwesterly direction and empties into the Mississippi near the present city of Cairo. Its total length of 967 miles forms the dividing line between the States of Ohio, Indiana, and Illinois on the north and Kentucky and West Virginia on the south. The chief tributaries from the north are the Beaver, Muskingum, Scioto, Miami,

and Wabash Rivers; tributaries from the south are Kanawha, Licking, Kentucky, Green, Cumberland, and Tennessee Rivers.

The total area of the watershed drained by the Ohio and its tributaries is 203,000 square miles and constitutes the major portions of the States named above (except Illinois) and smaller portions of New York, Tennessee, Alabama, Illinois, Pennsylvania, Virginia, and North Carolina.

This watershed is in general characterized in the eastern part by rugged, hilly country, with comparatively small flood plains and level areas. But in the lower and western portion the general ruggedness gives way to comparatively large stretches of rolling or nearly level areas along the less rapid main stream or its larger tributaries, notably the Wabash.

The geographical position of the main stream is such that tributaries of the upper portion are subject to rather rigorous winter conditions, with the result that spring thaws produce high floods, which erode the banks and scour the channels of tributaries and of the main stream and carry very large amounts of suspended matter and silt downstream. Fluctuations of level and consequent erosion in the upper portions are further induced by the general ruggedness of the watershed and the relatively steep slopes of the channels. On the other hand, such tributaries as the Cumberland and the Tennessee Rivers, coming from the south and joining the Ohio in the less rugged lower portion, are not subject to such extremes of temperature and level.

The channel of the main stream is characterized by numerous islands, bars, wide shallow riffles, and a few deep pools. Hills noted for their beauty adorn either bank. Flood plains are few and comparatively small in size. There are no extensive back-water areas, with the result that there is little opportunity for flood water to be retarded by temporary overflow on such lowlands. These natural checks of turbulent, destructive floods are practically absent in the upper two-thirds of the Ohio channel, and are but few even in the lower portions.

These natural conditions are modified somewhat by the numerous dams that have been constructed along the river. These now number 38, and more are being built. Most of them are of the "bear-trap" type, so constructed that they may be laid down, allowing the water to flow over their sills without obstruction; or at low stages they may be raised, forming pools of sufficient depth for river transportation purposes. Ultimately, by the aid of these dams, the river will be navigable from mouth to the source at Pittsburgh, and the series of pools thus formed will profoundly affect the biology of the stream.

The main sources of direct sewage pollution of the Ohio River are the metropolitan districts of Pittsburgh, Cincinnati, and Louisville. Relatively small amounts of polluting matter, chiefly sewage, are contributed by Wheeling, Huntington, Portsmouth, Evansville, and Paducah. Certain tributaries whose well-populated valleys find convenient disposal of their sewage in the local stream tend to increase by a small margin the load already carried by the main stream. This is true of the Beaver River, also of the Scioto. The majority of the tributaries, however, tend to dilute, rather then to concentrate, the sewage content of the Ohio.

The initial pollution at Pittsburgh consists essentially of the untreated sewage from a population of 1,000,000, in round numbers, together with a large amount of industrial wastes, details of which will be given elsewhere in the complete Ohio report. The second heavy pollution occurs at Cincinnati, where the river receives the untreated sewage from more than half a million population. However, in the 480-mile flow from Pittsburgh the stream has largely recovered from the initial pollution and has been augmented by tributaries until the volume of water at Cincinnati is more than four times that at Pittsburgh. Similarly, at Louisville the pollution incident to a population of 300,000 is received by the stream which, after a flow of 120 miles from Cincinnati, has been increased measurably by the advent of the relatively clean Miami and Kentucky Rivers, thus increasing, rather than diminishing, its capacity for the disposal of the organic matter received at Louisville.

THE PITTSBURGH DISTRICT.

In brief, certain of the factors that may affect the biological situation at Pittsburgh are:

Two streams, the Allegheny from the north and the Monongahela from the south, with unequal volumes of dissimilar waters, unite to form the Ohio.

The Allegheny, contributing 60 per cent of the water, is characterized by severe winter conditions, a quick-spilling basin, steep and uniform slope, widely scattered population and points of pollution, and a short time-factor for biological action in the 24-mile slack-water basin formed by three dams just above Pittsburgh. The water is alkaline and usually turbid.

The Monongahela, contributing 40 per cent, has comparatively mild winter conditions. Floods from the quick-spilling basin are checked by the 131-mile slack-water stretch formed by continuous dams, which thus insure a long time-factor for sedimentation and biological reduction of sewage and waste from a large and concentrated population and from industrial establishments lining the river

banks. The water is generally acid from mine drainage and but slightly turbid.

A slack-water basin extending nearly 5 miles below Pittsburgh (except during high water) receives these two tributaries, together with large amounts of untreated sewage and industrial wastes discharged directly into this basin along Pittsburgh's total water frontage of 31½ miles.

Finally, abundance of organic material in various stages of decomposition, restored alkaline reaction, and a considerable time element constitute a favorable environment for biological action at this point.

Samples were taken from each of the two rivers at points some distance above the point of confluence and above the portion of the Pittsburgh water front where sewage and wastes are added to the river. The sampling point for the Allegheny River is 7 miles upstream from the confluence of the two streams, and is designated by A–7. The Monongahela sampling point is 12 miles above the confluence and its designation is M–12. At O–3, 3 miles below the confluence, samples were taken to ascertain the content of the mixed waters. Similarly, O–23 designates a sampling point sufficiently far below Pittsburgh to insure thorough mixture, as well as a considerable time interval for biological action and sedimentation, through the agency of five successive pools formed by as many dams. Samples were also taken in the mouth of the Beaver River, which enters the Ohio 25 miles below Pittsburgh.

Water from these five sampling points show the biological condition of the streams on reaching the Pittsburgh district, but before the access of sewage and wastes from the city itself; after the two tributaries combine and have meantime received sewage and industrial wastes in large amount from Pittsburgh; after the complete mixing, sedimentation, and detention caused by the five dams; and at the mouth of the Beaver River.

The average results of weekly examinations made during the months of August, September, and October, 1914, are given in Table No. 6 (p. 53) and the principal features are shown graphically in plankatograph No. 1 (p. 58).

Station M–12.—Ten weekly samples taken at M–12 during a period of relatively stable conditions of temperature, river stage, and turbidity showed a relatively constant content of organisms, both as to amount and kind. Organisms averaged 5.3 to 6.4 per cent of catch (monthly averages). Rotifers constituted 89 to 96 per cent of all organisms present. Lack of variety and total absence of green algæ further characterized the plankton.

This sampling point, located near the lower end of the 131-mile slack-water stretch, represents water which has been subject to heavy pollution by sewage, by industrial wastes, and by drainage from coal

mines. But it has also enjoyed the great advantage of a long time-factor. Except for one item, this combination of factors would, in all likelihood, insure great productiveness and activity among the plankton organisms, for food is abundant and the impounded water gives ample time and quiet for reproduction. The factor whose effect is not definitely known is the mine drainage and the pickling wastes from steel mills, which tend to make the water acid in reaction. The bacterial content of the water is very low and out of all proportion to the large amounts of pollution entering the river. It is extremely probable that any substance thus toxic to bacteria would to an appreciable extent affect the plankton forms also.

Further data, and laboratory experiment as well, are necessary before it may be said in just what manner this unfavorable environment affects the smaller organisms of the plankton. The effect may be direct, especially to plantlike organisms, resulting in the more or less speedy death of these minute forms when the water in which they have been reared is presently mingled with that in the lower part of the slack-water basin where the reaction is prevailingly acid. Or the effect may be exerted indirectly by the killing off of the bacteria which form a large part of the food supply of many of those plankton organisms which ingest food particles rather than absorb dissolved material as do plants. Regardless of the acidity of the water, these organisms could not be present in numbers when their chief food supply is not to be found. It has been observed repeatedly (Kofoid, 1904, pp. 116, 117, 120) that such forms as those mentioned above disappear from the water when a considerable degree of purification is indicated by the diminishing numbers of bacteria. There is a vital relationship of some kind existing between them.

Plankton is abundant at M–12, however, but it is limited to a very few organisms. Rotifers constitute 89 to 96 per cent of all organisms found, and these rotifers are of two kinds only.

It seems reasonable to assume that these narrow limits as to variety of organisms which comprise the plankton are the result of some unfavorable influence which eliminates all forms except these few varieties.

The question of food supply for some of these organisms is a matter of interest. The most abundant rotifer, *Brachionus*, is herbivorous, or, at any rate, omnivorous, in common with most of the ploiman rotifers (Kofoid, 1904, p. 145), and is thought to find most of its food in phytoplankton, that is, minute chlorophyll-bearing organisms. But these minute organisms were not found at all in the samples. It is possible that the difficulties of recognizing them in the preserved catch might account in part for this result, but such human limitations would not give wholly negative results in every sample examined.

It seems probable that these rotifers would find their chief food supply in the abundant organic matter in suspension in the water incident to heavy sewage pollution and incident, further, to the absence of sufficient bacterial life to dispose of this material.

We thus see at M–12 the unusual spectacle of a plankton which has responded to the very favorable conditions of environment, abundant food, and very long time-factor, but which has meantime been subject to some biological catastrophe which has nearly or quite eliminated the first few links in the chain of organisms whose interdependence arises from their food relations. The resulting plankton is large, but consists of a very small variety of the larger organisms—the biological end-product of the complicated reactions due to the dominant factors of abundant food, long storage, and, probably, acidity of water at this station.

Station A–7.—In the Allegheny at Station A–7 during the same period the temperature ranged from 24° C. to 16° C., turbidity from practically zero to 60, and river levels recorded by the gauge at Freeport, Pa., fluctuated from 0.7 to 2.2. The monthly average plankton content varied from 0.2 to 1 per cent of total catch.

Rhizopods held leading place in September and diatoms in October Noticeable features of plankton were variety of organisms present, unusual scarcity of organisms in August samples, and relatively small plankton yield at all times.

The water is of comparatively recent origin owing to the gradual and considerable slope of 2 feet per mile in the lower 85 miles of this river and owing, further, to the absence of any slack-water basin that is sufficient in size to impound the large discharge of this stream for more than a short period. The river is thus very sensitive to flood conditions, and consequently the short slack-water stretch just above Pittsburgh is subject to quite frequent renewals of the water. This condition is disastrous to plankton life generally (Kofoid, 1903, p. 458) by preventing that adequate decay of sewage which would furnish plankton life with abundant food and, further, by providing a time-factor which is far too short for the breeding of plankton in quantity. The partially decayed organic material, together with such plankton as may be present, are swept on into the Ohio by the frequent floods.

Conditions similar to the foregoing were found in the study of the Illinois River by Kofoid (1903, pp. 349, 458). The plankton production of a certain tributary (Spoon River) averaged only one-fiftieth that of the main stream, and the only available explanation was found in the fact that the water of the tributary was of recent origin and the relatively rapid current caused such frequent renewal of the water that there was insufficient time for the breeding of plankton in this tributary stream. Kofoid concluded: "*The age of*

the water is, other things being equal, one of the most vital of all the hydrographic factors environing the plankton."

The organisms found in samples at Station A–7 apparently reflect the varied and somewhat unstable conditions of environment.

For some reason not apparent, August samples yielded very few organisms. Turbidity had reached a maximum of 90 the day preceding our first collection, although the gauge at Freeport showed a rise in levels of only 2 feet. It is possible that this influx of turbid water, probably from some tributary, reacted unfavorably on August plankton.

September samples reflected the moderate disturbance of river levels by showing predominance of the rhizopods *Difflugia* and *Arcella*, both of these organisms belonging normally to bottom sediments or to the surface of decaying plants or other organic matter. Their prominence in plankton samples is usually a function of disturbed conditions of stream flow. Holophytic (plantlike) organisms are moderately abundant as a result of comparatively low turbidity, premitting access of sunlight. In turn, the rotifer *Anuræa*, which feeds principally on minute plant life, is present in small numbers. *Anthophysa*, a colorless flagellate, usually abundant in contaminated water, is present also.

Cooler temperatures in October favor the growth of diatoms, which are found moderately abundant. A rise in water levels brought the bottom-loving organisms *Difflugia* and *Arcella* again into the plankton in the last sample, together with a large amount of suspended matter.

Station O–3.—Ten weekly samples taken at O–3 during this period of very moderate fluctuation as to temperature and turbidity show a monthly average plankton content of 7.6 to 8 per cent of the total catch.

Organisms present show moderate variety, rotifers predominating, comprising 91, 66, and 61 per cent of all the plankton forms in the three months, taken in order. Ciliates appear in moderate numbers. Crustacea and diatoms are present in small numbers. Neither diatoms nor algæ appear in August, both are found in September, and algæ again in October.

Hydrographic conditions were so nearly uniform and stable that the plankton catches may be regarded as truly representative of prevailing low-water conditions at this station—the first in the Ohio River proper.

Abundance of plankton in all catches means that suitable food for these organisms is plentiful. This necessity is evidently supplied partly from the two tributary streams that unite to form the Ohio River and partly from the great volume of sewage and industrial

waste contributed along the Pittsburgh water front. It is evident that this organic matter thus supplied from these sources will vary greatly in age and in stage of decomposition; that from the Monongahela having been subject to a very long time period, but in water of acid reaction; that from the Allegheny River representing a variety of ages on account of the widely scattered locations of the towns on its watershed; and, finally, the sewage and waste from Pittsburgh representing a comparatively fresh condition.

It would seem that this organic material of different kinds, of different ages, and hence in various degrees of decomposition, would supply all necessary food requirements for a large and varied assortment of plankton organisms.

The slack-water basin formed by the dam a short distance below this sampling point provides comparatively still water along the entire Pittsburgh water front, thus imposing on the mingled waters forming the Ohio River a moderately long time-factor which would tend to encourage biological activity. This, with the presence of abundant food, should produce a heavier growth of plankton than we find at O–3.

Reference to the chemical data reported in another section will show that during August, September, and October, when our samples were taken, the acidity of the Monongahela had been neutralized by the alkaline water of the Allegheny and the acid salts of the Monongahela had been largely eliminated. There are probably many reactions and adjustments taking place of which we have no direct knowledge. We know only these end reactions or the final outcome.

This beginning of the Ohio River at Pittsburgh is evidently the arena in which the dissimilar waters of the two tributaries settle their differences of chemical reaction and physical condition and acquire the final adjustments which appear in samples taken at O–11, this final outcome being hastened, or variously modified, presumably, by the large amount of industrial wastes and sewage introduced at Pittsburgh.

It seems highly probable that the acidity of the Monongahela might at times be a factor at O–3, for occasional acidity was noted in daily samples at O–11, where chemical samples were taken. This probability is strengthened, moreover, by the fact that during one month of this period (August) the discharge of the Monongahela was 2,070 second-feet and that of the Allegheny was 1,660 second-feet, a reversal of the usual order of relative discharge of these streams.

Any such occasional acidity at O–3 would be likely to exert unfavorable influence on the development of plankton life, as is the case at M–12. Moreover, the various changes in the concentration of dissolved materials (including acid salts) that must be a part of the process of readjustment in this physiochemical arena would un-

doubtedly show a biological reflection in a decreased plankton production.

The plankton-poor water of the Allegheny will function as a diluent of the more abundant plankton contributed by the Monongahela. Inasmuch as the usual discharge of the Allegheny is considerably in excess of that from the other tributary, it is no surprise that the plankton at O–3 reflects this diminished relative value and, to some extent, shows something of the variety of organisms which characterizes the scanty plankton contributed by the larger stream.

Abundance of organic matter is indicated at O–3 by the prevalence of the same rotifers, *Brachionus* and *Rotifer vulgarus*, which we find predominant at M–12. Distinctly pollutional organisms, *Anthophysa* of the Mastigophora and *Vorticella* and *Epistylis* of the Ciliata, appeared in five samples. *Vorticella* formed 29 per cent of the entire catch in one of these samples and from 1 to 9 per cent in three other samples. *Rotifer actinurus*, a pollutional organism (Forbes and Richardson, 1913, pp. 502, 513), appeared in moderate abundance in 1 sample, while in 7 of 10 samples the contaminate *Rotifer vulgaris* was abundant.

Station O–23.—At Station O–23, 10 weekly samples taken during a period of relative quiet as to water conditions show a moderate assortment of organisms. Rotifers predominate in two months and crustacea in one. Diatoms are abundant in one August sample Green algæ, Mastigophora, and ciliates are present in rather small numbers. A noticeable feature of collections here is the decline of rotifers as the leading plankton and the gradual advent of crustacea.

Diatoms (*Synedra delicatissima*) are abundant in one sample only, that of August 25. Temperature was 24° C. The sudden appearance of this organism, which is usually more abundant in cool weather than in warm, seems to be without explanation except for the fact that the "bear traps" had been lowered a few days before and the pools were drained of some of their surface water. This disturbance and readjustment of levels might be responsible for the appearance at this station of the relatively large number of diatoms whose growth and multiplication had probably taken place in some sheltered bit of water in one of the upstream dams. It is worth noting, also, that an unusual number of *Brachionus* (the same rotifer that is so abundant at O–3 and at M–12) appeared in this same August sample at O–23. The lowering of the "bear traps" was reported August 18, one week before this sample was taken.

The list of organisms, together with relative abundance of certain kinds, indicates some improvement in the water. Two organisms of recognized pollutional affinities, *Euglena viridis* and one of the *Vorticellidæ*, were present in moderate amount in one sample, and a very few of the former organism in a second sample. However, the pres-

ence of *Brachionus* in 5 of the 10 samples would indicate sufficient organic matter to furnish food to this rotifer, which is classed by some writers as a contaminate organism. (Eyferth, 1909, p. 534.) On the other hand, the better condition of the water is attested by the fact that the pollutional rotifers *R. actinurus* and *R. vulgaris*, which were fairly abundant at O–3, are entirely absent here; the pollutional protozoa *Anthophysa* and *Epistylis* are likewise absent. Moreover, a rotifer of recognized cleaner water environment, *Anuræa* (Kofoid, 1904, p. 151), is here found in four samples, while it was entirely absent at O–3. The minute algæ which constitute much of the food of this rotifer is present at both O–3 and O–23.

Perhaps the most notable feature of plankton at this station lies in the fact that, while rotifers hold first place quantitatively in August and September, the crustacea (*Cyclops*) assume this rôle in October and maintain it, as far as rotifers are concerned, in plankton collections farther down the river at Wheeling. In food habits *Cyclops* is a scavenger (Herrick, 1884), and its presence means the destruction of much of the organic matter that has thus far escaped or survived the attacks of bacteria, ciliates, and certain rotifers.

This station is in the lower part of pool formed by Dam No. 5, hence, between the last station considered, O–3, and this point intervenes a stretch of 20 miles of water, all of which is impounded by Dams Nos. 1 to 5, inclusive. According to data given in the hydrometric section of the full report,[1] the time of flow between these two stations was 5.59 days in August, 6.20 in September, and 12.49 days in October 1–15. It will thus be seen that the time interval concerned is out of all proportion to the distance traversed. That this very slow movement of water provides sufficient time interval for considerable biological activity would seem to be demonstrated by the fact that the plankton at O–23 is reduced in net amount and changed in regard to the predominating organisms.

Beaver River.—Samples from the Beaver River show a varying and rather abundant plankton made up of a well-balanced variety of forms and contributing from 4 to 13 per cent of the total catch.

Diatoms appear in every catch and are relatively abundant in eight catches, forming from 17 to 86 per cent of all organisms in the respective catches, the larger values being confined, with one exception, to the cooler temperatures of the last four weeks, September 15 to October 15. *Synedra delicatissima* was most abundant, appearing in every sample but one and forming the bulk of the entire catch in the last four samples, seemingly favored by the cooler weather. *S. biceps* and *S. ulna*, the latter classed by Senft (1905) as a pollutional organism, were present in moderate numbers in nearly all samples.

[1] Not yet published.

Minute green algæ, consisting of fragments of very small filamentous forms together with the unicellular *Pediastrum* and *Scenedesmus*, formed from 2 to 27 per cent of organisms in nearly all the catches. Small amounts of blue-greens were found in four samples. Chlorophyll-bearing flagellates of the Mastigophora, chiefly *Euglena viridis*, *Dinobryon*, and *Phacus*, were present in similar amounts. The diatoms, algæ, and green flagellates thus aggregate a volume of synthetic or plantlike organisms which is somewhat greater than the volume of plankton animals, as will be seen.

Of the plankton animals, *Difflugia*, a bottom rhizopod, was present in two samples, one of which was taken during rising levels and the other following the crest of a rise. Ciliates were represented by *Codonella* and *Tintinnus*, sparingly found in two samples. This scarcity of ciliates, which are usually abundant in contaminated water, is surprising, in consideration of the fact that the presence of pollution is indicated by *Euglena viridis* in a majority of the samples, and a similar organism, *Phacus*, is found in four samples.

Three samples contain the rotifer *Brachionus* in small to moderate numbers, and the contaminate rotifer *R. vulgaris* was found in two samples, but in small numbers. The rotifer *Anuræa cochlearis*, which is not characteristic of great pollution but abounds in water containing only moderate amounts of organic matter, was moderately abundant in 8 of the 10 samples. It is noticeable also that the minute chlorophyll-bearing organisms that form the greatest part of the food of this rotifer (Kofoid, 1904, p. 151) were found in all samples but one.

Crustacea appeared sparingly in two samples only. *Cyclops*, the leading form, thrives best in a stable environment as to water movement. (Kofoid, 1904, pp. 260, 267.) The mild but frequent fluctuations of the Beaver River during this period may explain, in part at least, the scarcity of crustacea. These disturbances of water levels will also explain the presence in four samples of a few nematode worms which normally live in bottom ooze or in decaying matter which would be disturbed by fluctuating movements of water.

The relatively heavy plankton of the Beaver River, averaging 4 to 13 per cent of the average total catch, indicates that conditions are, on the whole, favorable for plankton production. The one unfavorable condition thus far observed is found in the somewhat unstable hydrographic conditions. The fact that this does not seem to interfere with the presence of relatively abundant plankton would seem to indicate that other vital factors of plankton production are at their best, thus compensating in some degree for the unfavorable condition mentioned. It is therefore evident that food, in all probability sewage, is present in considerable amount, and in such stages

of decomposition as will best suit the requirements of such organisms as constitute the plankton. Toxic conditions, such as the acidity of water, which apparently limits to a few resistant organisms the plankton of the Monogahela River, are evidently absent from the Beaver River, for a large variety of organisms is included in the list of plankton.

Bottom deposits.—In addition to the samples of water taken for examination, a series of 20 samples of bottom mud was collected for the study of the life upon the bottom of the stream. The samples represented four of the five stations of this district, it having been impossible to obtain any mud at the bottom at Station O–23.

The tubificid worm, *Limnodrilus*, characteristic of sewage pollution, was found at each of the stations, but in increasing numbers with increasing pollution. It was comparatively rare in the Monongahela, and present in great abundance at Station O–3.

Some *Chironomus* larvæ and the associated form *Tanypus* were found occasionally.

In general, results are what might be expected from the known facts concerning the condition of pollution of the waters. The unfavorable effect of acidity is also observed, although here again it can not be stated whether this effect is primary or secondary.

SUMMARY OF BIOLOGICAL CONDITIONS IN THE PITTSBURGH DISTRICT.

The nearly equal urban and sewered populations of the two contributing watersheds tend to produce waters that, without consideration of other factors, upon their arrival at Pittsburgh are similarly contaminated. But the great variation of climatic, physical, and other factors make of the two streams distinctly different biological habitats. Prominent among these differences are geographical position, size of catchment area, slope of valley, detention of water by pools and dams, amount and kind of industrial wastes and mine drainage, and, finally, the distribution of population with reference to the time of flow from the points of pollution to the confluence at Pittsburgh.

The average yield of plankton in the lower Monongahela is considerably greater than that of the lower Allegheny. This condition is ascribed to the long storage period to which the Monongahela water is subjected, and the resulting age of the water, permitting extensive development of plankton life in the nearly motionless waters rich in the accumulated products of decay of organic matter.

But this heavy plankton is limited to a small assortment of organisms, presumably because the acid condition of the water kills off the smaller ones and the less resistant of the larger forms, both plant and animal, leaving to few surviving varieties the very large

supply of rich food that must be present in this old and heavily polluted water. The possibility of an acquired immunity having resulted from continuous exposure of successive generations to the acidity of the water is an interesting biological contingency.

The smaller plankton yield of the Allegheny seems to be due chiefly to water movement and consequent frequent replacement of water by that of more recent origin, thus cutting short the time period required for plankton production and for the requisite degree of decomposition of organic matter which results in suitable food for plankton organisms.

The waters, on combining, are subjected to a further time period of two to four days in reaching Station O–3, receiving in the meantime a large amount of sewage and of various industrial wastes along the Pittsburgh water front. The plankton at this station is not as large as conditions of food supply and time-factor seem to warrant, the discrepancy being due, in all probability, to the presence of harmful substances among the numerous industrial wastes discharged into the river. Before O–23 is reached Dams Nos. 1 to 5 have impounded the water for an additional period of 5½ to 12 days. The resulting plankton at O–23 is reduced in net amount and changed in character.

Organisms at M–12 can hardly be regarded as characteristic of pollution, except one rotifer (*R. vulgaris*), which is so classed by Eyferth (1909) and was found in 7 of the 10 samples.

The small amount of plankton at A–7 exhibits a varied assortment of organisms which do not, as a whole, indicate pollution. One distinctly pollutional organism is relatively abundant in one sample and is present in a second.

In plankton from O–3 distinctly pollutional and contaminate organisms are present in every sample but one.

Plankton from O–23 shows known pollutional organisms in two samples. The presence of the cleaner water rotifer *Anuræa* in four samples, together with the decline of rotifers as a class and the corresponding increase of crustacea, are significant of some improvement in the water since leaving Station O–3.

The Beaver River yields an abundant and well-assorted plankton, in which diatoms predominate. The rotifer *Anuræa* is found in most samples. Pollutional organisms are present in moderate and small numbers in 8 of the 10 samples.

Mud samples give throughout evidence of pollution.

TABLE No. 3.—*Organisms of bottom mud as a pollution index of Ohio River.*

District.	Sampling station.	Time interval included.	Number of mud samples 200 c. c. each.	Pollutional organisms.		Doubtful and indifferent organisms.	
				In all mud samples; total number.	Average per sample.	In all mud samples; total number.	Average per sample.
Pittsburgh	M-12	August to Oct. 15, 1914	4	[1] 12	3	0	
	A-7	do	5	189	38	14	3
	O-3	do	5	2,909	582	4	1
Wheeling	No mud found.						
Portsmouth	349	August to Oct. 15, 1914	4	22	5	10	3
	358	do	4	10	3	28	7
Cincinnati	461	July 20 to Nov. 20, 1914	9	4		22	3
	475	July, 1914, to November, 1915.	61	5,566	91	137	2
	492	September 1914, to December, 1915.	3	36	12	15	5
Louisville	588	do	60	726	12	483	7
	619	September, 1914, to Apr. 30, 1915.	4	80	20	101	26
Paducah	904	September to Oct. 15, 1914,	4	11	3	12	3
	920	do	2	0		5	3
	933	do	5	1		7	1
The start at	O-3	August to Oct. 15, 1914	5	2,909	582	4	1
The finish at	933	September to Oct. 15, 1914	5	1		7	1

[1] Small number of organisms may be due in part to acid condition of water.

THE WHEELING DISTRICT.

The significant features in the biological situation in the Wheeling district are these:

The water from the Pittsburgh district, contaminated with sewage and industrial wastes, with some inhibitory influence by the acid water of the Monongahela, has been exposed to 95 miles of flow, the time interval of which will vary greatly, according to the stage of the river.

Twenty-five miles below Pittsburgh the Beaver River, draining 3,000 square miles, enters the Ohio.

A moderate amount of comparatively fresh sewage and industrial waste from two districts 50 and 70 miles, respectively, below Pittsburgh affects the water.

Sewage and industrial wastes from Wheeling constitute a moderate secondary contamination. This is lessened somewhat by the preliminary treatment afforded a portion of the sewage and slaughterhouse refuse by the septic Wheeling Creek.

Dam No. 13 forms an 11-mile slack-water basin extending along the Wheeling water front and several miles above the city. A population of about 75,000 contributes untreated sewage. Industrial wastes, consisting of slaughterhouse refuse, waste from steel mills, and some mine drainage, are discharged along both sides of the water front. Most of the slaughterhouse waste is first discharged into the

backed-up water of Wheeling Creek, which is bubbling and offensive in consequence of the septic action resulting.

Three sampling stations were utilized in the study of the waters of this district. The upper station, O–65, is 40 miles below the mouth of the Beaver and 25 miles above Wheeling; the middle station, O–77, lies between Steubenville and Wheeling; and the lower station, O–97, is at the lower end of the basin formed by Dam No. 13 and about 6 miles below Wheeling, all in slack water at low river stages.

Samples were taken at weekly intervals from each of these stations during August, September, and October, 1914. The hydrographic conditions were unusually stable. The average results of these examinations are recorded in Table No. 1, page 14, and the principal features are shown graphically in planktograph No. 2.

Station O–65.—This station yielded a moderately light plankton containing few pollutional organisms, but with crustacean scavengers rather abundant.

The Beaver River and East Liverpool, 20 miles above this point, constitute the only recent pollution. The Beaver River increases the volume of the Ohio by about 10 per cent and contributes a heavy plankton made up of a varied assortment of organisms. After 40 miles of flow and with these influences at work the station under consideration yields a plankton which differs from that at Station O–23 in being less abundant and in showing better biological balance.

Three dams are located in the stretch between the mouth of Beaver River and Station O–65. The impounding action is accentuated by the low water levels prevailing in the Ohio River during this period.

The hydrometric studies show that the mean time interval between O–23 and O–65 during 1914 was 4.9 days in August, 6.14 days in September, and 11.35 days in the first half of October.

Station O–77.—The important features of the results at Station O–77 as contrasted with those at Station O–65 are the greater abundance of plankton, the increased proportion of crustacea, the higher numbers of diatoms and lower numbers of algæ, and the regular occurrence in small numbers of *Euglena viridis* of recognized pollutional habitat.

The two stations are essentially similar in regard to the organisms that predominate. In both, diatoms lead, except in August at Station O–77, and crustacea are abundant, exceeding the rotifers in total volume.

The relatively large amount of plankton is significant, considering the fact that thus far there has been a successive and consistent decrease as the Stations O–3, O–23, and O–65 are reached. It is indicated, therefore, that the steady decrease in plankton content noted in the upper stations was due to food exhaustion, and that

this decrease has been temporarily arrested by the addition of a considerable amount of sewage from Steubenville and Wellsburg.

Station O–97.—Notwithstanding access of sewage and industrial waste from Wheeling and the slight impounding action of Dam No. 13, plankton at O–97 showed a decrease, instead of an increase, as compared with plankton from O–77.

Differences in the biological balance and in the predominating organisms give somewhat uncertain evidence of the activity of some unfavorable factor which may be responsible for the lack of normal increase in plankton.

Few pollutional organisms are present. Crustacean scavengers are abundant, however. Cleaner water organisms are moderately abundant.

Bottom deposits.—Repeated dredgings at each of the stations of this district failed to bring to the surface anything but clean sand and gravel.

SUMMARY OF BIOLOGICAL CONDITIONS IN THE WHEELING DISTRICT.

At O–65 the relatively light plankton indicates the gradual exhaustion of available food since leaving the last Ohio station at O–23. Thus, despite added pollution from the Beaver River and from East Liverpool, biological purification of the river is well under way at this station, only 65 miles below Pittsburgh. This fact is further shown by the character of the prevailing organisms. Pollutional forms which indicate recent addition of sewage (ciliates and certain flagellates) are few in number, while organisms which are equally characteristic of the presence of old and relatively stable organic matter (diatoms and crustacea) are abundant.

Another matter that speaks well for the betterment of the water is the appearance, for the first time in the Ohio, of biological balance among the plankton organisms. This means a considerable assortment of food materials in various stages of disintegration which permits the existence of a large variety of forms well distributed among holophytic, or plantlike, and holozoic, or animallike, organisms. Biological balance also means absence of any particularly destructive agency, such as toxic material. It means also the presence of such amounts of sunlight, of dissolved gases, and of dissolved salts as may be required for those plantlike organisms which constitute the first links of what Kofoid calls "chains of food relations," the succeeding and final links of which are made up of higher animals.

The Wheeling district as a whole represents the stabilizing of the water as expressed in the prevailing biological balance. As the water leaves this district on its 250-mile trip to the next sampling station

it is in more nearly normal and stable condition, judged from a biological point of view, than when it left Station O–23 in the Pittsburgh district.

THE PORTSMOUTH DISTRICT.

Portsmouth is located at the confluence of the Scioto with the Ohio, 355 miles by river below Pittsburgh. Between Wheeling and Portsmouth, a distance of about 265 miles, the Ohio receives comparatively little sewage pollution either directly or through its three tributaries of consequence, the Muskingum, the Kanawha, and the Big Sandy. These three tributaries, together with several smaller ones, increased the volume of water in the Ohio by about 167 per cent between Wheeling and Portsmouth during the period covered by these examinations.

At Portsmouth the Ohio receives the sewage of the city (which is insignificant in proportion to the discharge of the river) and also the waters of the Scioto, draining 6,500 miles and bringing sewage from Columbus, Marion, Circleville, and Chillicothe, aggregating a population of 220,000. Columbus and Chillicothe, the points of chief contamination, are 130 and 60 miles, respectively, above Portsmouth.

The organic matter of the water reaching Portsmouth has undergone the effects of time and dilution afforded by the extended flow from the last station and the advent of large tributaries which add comparatively little pollution.

The movement of water from Wheeling is comparatively rapid in a channel which consists of a succession of islands which divide the current, shoals and riffles which spread the water in a thin sheet, bars which deflect the stream from one side or the other, and pools which retard the movement, a natural mixing arrangement typical of the Ohio River. Two dams controlled by locks also assist somewhat in the impounding and mixing process.

Three stations were selected for the biological studies in this district. Station O–349, 6 miles above the city of Portsmouth, is representative of the water previous to its pollution in noticeable quantities. Station O–358, below the city, gave representative samples of the water after passing the city and as affected by the rather extensive pollution of the Scioto. The Scioto itself was further studied at a station located at its mouth.

The average results of weekly examinations in August, September, and October, 1914, are given in Table 6, and the salient features are shown in graphic form in planktograph No. 3.

Station 349.—Collections at station 349 show large reduction in plankton as compared with the results below Wheeling, evidently due to a gradual exhaustion of the food supply. There is also

noticeable lack of animal forms and almost total lack of pollutional organisms.

The Scioto River.—It is evident that environmental conditions are more favorable for biological activity in the Scioto than in the Ohio at Station O–349, chiefly in the matter of food supply resulting from the discharge of sewage into this relatively small stream at Columbus, 130 miles upstream, and Chillicothe, 60 miles above the mouth. But even this Scioto plankton yield is light. Animals are only moderately abundant and plants, especially minute green algæ, are unusually prominent. This comparative lightness of plankton and the relative abundance of plant life over animals point to the age of the pollution and the considerable degree of decomposition already reached by the contained organic matter. Very few pollutional organisms were found.

Station O–358.—The plankton at station 358 was very similar in kind and amount to that at station 349, but shows slight increase in total volume, evidently due in part to addition of food from the sewage of Portsmouth, and particularly to the heavier plankton of the Scioto River.

Bottom deposits.—In addition to the water samples that were collected and examined, there were taken in this district four samples of mud from the bottom at each of the Ohio River stations and three from the bottom at the mouth of the Scioto.

All these samples gave essentially the same findings, namely, moderate numbers of *Limnodrilus* almost constantly present, with the larvæ of *Chironomus* and the associated *Tanypus* frequently present. Numerically interpreted the results are consistent with the known conditions of moderate pollution. The physical condition of the samples would also go to confirm this finding.

THE CINCINNATI DISTRICT.

The next stretch of the river at which biological studies were carried on is the section of which Cincinnati is the center. The points of chief interest in determining the biological conditions of this district are briefly summed up as follows: The grossly polluted water of the Pittsburgh district has been subjected to a flow of about 481 miles. The time of flow from Pittsburgh to Cincinnati (stated in monthly means covering the period of this study) was 38½ days for August, 1914, 39½ days for September, and 73½ days for the first half of October. During this interval of flow, tributaries have more than quadrupled the volume of water, and some additional sewage and industrial wastes have been added, notably by the Beaver River, at Wheeling, W. Va., and by the Scioto River. More than 100 miles of flow has intervened since the last appreciable accession of pol-

lution at Portsmouth, Ohio, the time of flow being about three days under the conditions existing during this study.

At Cincinnati the river receives a large amount of sewage and industrial wastes from an aggregate population of over 600,000.

At low river stages Dam No. 37 forms a slack-water basin which extends the entire length of the city water front, providing opportunity for sedimentation and biological action. During the summer and fall seasons of low water, mixing is aided somewhat by the movements of boats.

The stations selected for this study were five in number. Station 461 is well above the city and above the mouth of the Little Miami. The Little Miami at its mouth furnished the second station, and the mouth of the Licking the third. Station 475 is below the major influence of the city and near the lower end of the pool formed by the dam, and 492, the fifth station, is 11 miles below the dam and below the mouth of the Miami. The studies made at these stations were somewhat more extensive than those made higher up the river. The results are given in the form of quarterly averages of the weekly or biweekly examinations in Table 6.

Station 461.—The plankton at station 461 is small in amount and consists of ordinary organisms with a predominance of plant forms, with pollutional organisms practically absent.

The scarcity of pollutional organisms is evidently the biological reflection of the practical absence of recent sewage pollution. Portsmouth, the last point of sewage contamination, is 102 miles upstream, and its contribution amounts to little in the large volume of water. The predominance of plant organisms is likewise to be expected because of the presence of organic matter that is well reduced rather than fresh.

The amount of the plankton, though small, shows a substantial increase over the average amount at station 358, the increased organisms consisting largely of plants.

Stable conditions and low turbidity in November favored plankton development, especially diatoms.

High-water conditions and low temperatures during January, February, and March reacted unfavorably on plankton, resulting in small yield. In addition, many forms are partially dormant during this season. Plankton is necessarily a collection from various tributaries, sheltered backwaters, etc., that have been flushed out by high water.

In April and May, 1915, comparative stability of low levels, low turbidity, and rising temperatures caused some increase in plankton and started the "spring pulse" of diatoms.

June and July, 1915, were characterized by continuous high water and high turbidity. Plankton yield was small.

The Little Miami River.—At the mouth of the Little Miami the autumn samples show a light plankton and a marked degree of biological balance, except during high water. Green algæ, diatoms, rotifers, and ciliates are moderately abundant. Pollutional organisms are found in every sample.

Disturbed hydrographic conditions in December, January, and February resulted in light yield of native plankton and several species of adventitious diatoms. Pollutional organisms were present.

March, April, and May record lower turbidity, less disturbance of levels, and rising temperatures. Plankton yield increased steadily. Pollutional organisms appeared in most samples.

The Licking River.—The apparently erratic data from the Licking River constitutes a reflection of the extreme fluctuations of that stream, due largely to the "quick-spilling" type of its drainage basin. The cutting short of the time-factor by hydrographic disturbances, with the consequent interruption of plankton breeding, results in small yield of organisms and of fewer kinds, even when food supply is sufficient. Another aspect of the matter lies in the fact that rapid run-off and disturbances of level are direct causes of high turbidity which shuts out sunlight and prevents the development of those organisms which require light.

Station 475.—A very few diatoms were present. Algæ were slightly more abundant. The heavier organisms, *Difflugia* and *Tintinnus*, were moderately abundant, a condition to be expected when turbidity is high. Nematode worms were abundant in one sample following excessive turbidity. Pollutional organisms were *Anthophysa* in three samples, and small numbers of the rhizopod *Actinophrys* and the flagellate *Euglena* in one sample each.

The year's regimen of the Ohio at station 475 as based on the weekly plankton samples shows stability and low turbidity in the autumn and again in the spring. Fluctuating levels and high turbidity characterized the other seasons. A well-defined seasonal increase of plankton is found in the spring and another in the fall, the latter consisting chiefly of diatoms. Predominance of plantlike organisms during periods of hydrographic stability, and of diatoms during the disturbed hydrographic conditions of winter months, and an abundance of animals, especially the bottom forms, during times of high water and of marked turbidity, are also noted.

Pollutional organisms were present in a large majority (82 per cent) of all of the samples, most of these containing two or more forms of recognized pollutional animals or plants.

The results at station 492 are characterized chiefly by the marked increase in plankton yield during the fall over the yield at station 475. Few pollutional organisms are present during this period of quiet levels. Biological balance is in evidence. The very heavy plankton

was due largely to diatom growth. High water and excessive turbidity resulted in a light plankton during the winter. Favoring environment and seasonal influences resulted in an increase of plankton in the spring, during which time the "spring pulse" of diatoms occurs. The varied assortment of organisms shows some biological balance, but diatoms predominate. Pollutional organisms appeared in six of the eight samples. Continuous high water and excessive turbidity during June and July resulted in small plankton yields.

Bottom deposits.—Nine mud samples were secured from the bottom at station 461 during the period August to November, 1914. Of these, 3 contained no organisms, 2 a few *Limnodrilus*, 4 an average of 5 May-fly larvæ each, 2 a *Tanypus* larva, and a single *Ceratopogon* each.

At station 475, 84 bottom samples were collected during the period July, 1914, to December, 1916. From July to December, 1914, 33 of the 35 samples taken were mud, the remainder being sand with some slight admixture of mud. During the relatively high-water period of January to July, 1915, only 23 per cent of the samples were mud, and during the succeeding period of more stable conditions of flow, July to December, 1915, there was increasing deposition indicated by the fact that 57 per cent of the 23 samples were of mud, either wholly or in greater part. (See Chart No. 17.)

The most numerous organisms in the mud samples from this station were *Limnodrilus* and young bivalves, each of these forms being present, sometimes very abundant, in 33 of the 60 samples which contained mud. Not a sample during the first period was free from one or the other, while most of these samples contained both in abundance. The numbers were considerably smaller during the second period, when the bottom deposits were being swept away by high water, and during the third period no bivalves at all were found in any of the samples. High water had evidently removed them. The worm, *Limnodrilus*, would be less likely to be swept away in toto because of its well-known habit of retreating quickly into its burrow upon any disturbance. The mud must be removed in large quantities to dislodge them.

Other organisms present were *Tubifex*, *Æolosoma*, *Anthophysa*, and *Chætogaster* of the pollutional and contaminate forms. Of the indifferent and doubtful forms, *Chironomus* larvæ were the most abundant, occurring in 13 samples, usually in small numbers. Occasional samples of water snail (unidentified), leech, bryozoa, and larvæ of dragon fly (*Odonata*) and May fly (*Ephemera vulgata*) were found; also a single specimen each of sponge, planarian, and larvæ of *Corethra* and of caddis fly.

Bottom samples were taken at station 492 twice a month from September, 1914, to December, 1915. They showed that very little

mud can accumulate in this part of the river under normal conditions. Of the 49 samples only three consisted of mud, and these three were all taken during the unusually stable conditions in the latter part of 1914. All other samples consisted of clean sand and gravel.

Organisms in these samples consisted of *Limnodrilus* and young mussels chiefly. One *Chironomus* larva and one May-fly larva were found. The sewage worm referred to and young mussels were numerous in one sample. The other two samples showed these organisms in moderate and small numbers, respectively.

TABLE No. 4.—*Bottom sediments at station 475 as affected by river levels.*

	Time included.	Condition as to water levels.	Composition of samples.					Sanitary index of such samples as contained mud.				
			Mud.	Mud and sand.	Sand.	Sand and pebbles.	Total number.	Pollution.				
								Abundant.	Moderate.	Doubtful.	Absent.	Total.
I	July to December, 1914	Unusual stability	28	7	....	....	35	30	5	....	....	35
II	January to June, 1915	Disturbed levels	6	6	8	6	26	11	1	....	....	12
III	July to December, 1915	Moderate stability	8	5	8	2	23	10	3	....	....	13
	Total		47	13	16	8	84	51	9	....	....	60

SUMMARY OF BIOLOGICAL CONDITIONS IN THE CINCINNATI DISTRICT.

The principal biological facts of interest are shown in graphic form in the planktographs Nos. 4 to 8, and the general conditions may be summarized as follows:

The river on arriving at station 461 has, during stable conditions, over four times the discharge found at Pittsburgh. The water is reasonably free of organisms associated with pollution, judged by plankton and by bottom mud as well.

The Little Miami adds 2 or 3 per cent of moderately polluted water to the Ohio.

The Licking River, a little larger than the Little Miami, is subject to sudden floods from its quick-spilling watershed. Its water is often turbid and polluted. The frequent flushings carry into the Ohio a quantity of accumulated water and organic matter from the lower 2-mile slack-water portion of this tributary, whose plankton is as erratic as its unstable hydrography.

'Station 475 is just below Cincinnati, whose aggregate population of 595,000 has discharged its sewage into the river along a water front of about 12 miles above this station. Dam No. 37, located 6 miles below, forms a 21-mile pool which includes all of the city water front. Plankton, as compared with that of Pittsburgh, is light at station 475, and pollutional organisms are present in moderate numbers. This small yield is the natural result of the larger volume

of water (four times that at Pittsburgh), into which a little more than one-half as much waste is discharged, thus making the relative sewage dilution about one-eighth that at Pittsburgh. Also the time period for biological action (about one day) is too short for production of plankton in quantity. Biological balance is apparent.

Mud samples at this station indicate the presence of large amounts of organic matter.

The Miami River, joining the Ohio below Dam No. 37, adds about 5 per cent to the volume of water. Its plankton is light as a rule. It exhibits marked biological balance when conditions are favorable for plankton development.

Station 492 yields a plankton averaging about three times as heavy as that at station 475. This increase seems due to the lengthening of the time factor to two days or more. Biological balance is exhibited. The bottom deposits are scarce on account of strong current.

Seasonal fluctuations shown alike by the main stream stations are:

Very light plankton yield during low temperatures of winter, when water is high and turbidity excessive.

Heavy yield of organisms, especially plants, when turbidity is low and water quiet, even during cool weather.

Presence of bottom organisms in the plankton during time of flood.

Marked diatom pulse in November and a smaller one in April or May.

The situation at Cincinnati is very much simpler than at Pittsburgh. At the latter place two unequal tributaries unite their differing and contaminated waters to form a stream which is heavily polluted by the sewage and industrial wastes of Pittsburgh.

At Cincinnati a relatively normal water suffers a secondary contamination, which is proportionately about one-eighth as heavy as the initial pollution at Pittsburgh.

The noticeable differences in the biological results in the Cincinnati district are: Lighter plankton, fewer pollutional organisms, and greater evidence of biological balance.

The light plankton yield is evidently a result of the relatively smaller amount of contamination.

The prevalence of a condition of biological balance among the organisms constituting the plankton at the several stations in the Cincinnati district, especially at 475 and 492, is evidence of the prevalence of natural conditions; that is, adequate food supply and absence of toxic substances or other destructive agencies.

THE LOUISVILLE DISTRICT.

The water arriving at this district has been subjected to 130 miles of flow since leaving Cincinnati. This includes a period of quiescence

and sedimentation in two pools formed by dams. The Kentucky, a tributary of medium size, has added water containing but little sewage. Aside from this there has been no material addition of pollution since the water passed the mouth of the Miami.

At Louisville the water is thoroughly mixed by 2 miles of rapids. In addition to the mechanical aeration, the dissolved oxygen of the water is increased during the season of plant activity by the vigorous growth of submerged aquatic plants in many acres of shallow water above and over the rapids.

Sewage from a population of over 300,000 and large quantities of industrial wastes and stockyard refuse are discharged into the river along several miles of water front.

Two stations were established in the Louisville district for the biological studies; namely, at 598 and 619. Station 598 is at the intake of the Louisville water supply several miles above the direct effect of the city pollution, and at all times within the slack water behind the Louisville dam. The time of passage from the last station of the Cincinnati district, station 492, is shown in the hydrometric studies to have averaged 7.7 days in September and 17.8 days during the first half of October, 1914. Station 619 is below the rapids and below the full effect of the city pollution. At this station samples were taken at three points across the river to determine the effect, if any, of incomplete mixing of the pollution. The effect was not sufficient to justify separate tabulations of the results which are therefore averaged in the tabulated summaries. During the period of these studies the hydrographic conditions were somewhat disturbed in September, but constant at low levels during the first half of October, after which a further period of disturbance during November was followed by stable conditions up to the time of the high water, which lasted through the winter months. Quiet levels prevailed during the early spring, to be succeeded by flood conditions in June and July.

The results of the weekly examinations are given in the form of bimonthly averages in Table 6, and the more important items are shown graphically in planktographs 9 to 12.

Station O–598.—Summarizing briefly, the 11 months' collections at this station go to show the same seasonal variation and effects of disturbed hydrometric conditions as have been previously pointed out.

The beneficial influence of the long pool above Louisville is evident in that the time period thus imposed on the water results in prolonged sedimentation and biological activity. The approaching end reaction of the latter in the form of large numbers of crustacean scavengers attests the considerable degree to which organic matter has been "stabilized" or reduced toward a condition of comparative harmlessness.

Stable conditions in the fall permit heavy plankton production, which includes the fall "pulse" of diatoms.

High water, excessive turbidity, and low temperatures combine to check plankton growth until spring, when warmer water and stable conditions result in moderately heavy yield of organisms, including the spring "pulse" of diatoms and some pollutional flagellates. The disturbed conditions prevailing in early summer resulted in a plankton yield that was light and contained very few plants but many bottom organisms. Pollutional organisms were not especially abundant at any time during the 11 months.

Of the 47 samples taken, 17 were obtained during prevalence of stable conditions and low turbidity and the remaining 30 during flood conditions. Of the former, 18 per cent contained pollutional organisms in relative abundance, while of the latter samples 27 per cent contained these organisms in similar numbers. This would seem to indicate that flood waters, moving rapidly from flushed-out margins and tributaries upstream, arrive at station 598 with a greater number of pollutional organisms than are normal to the environment of this station during stable conditions. Hence, these high-water samples are not a reliable index of local conditions at this station, except in so far as they represent the flood conditions to which the river is subject during a part of each year and the consequent pollution of water incident to this flushing out of margins and tributaries.

Station O–619.—The collections at station 619 were characterized by somewhat lighter plankton content, the difference being chiefly due to the smaller numbers of crustacea present. It has been observed elsewhere in these studies that the crustacean *Cyclops* seeks the more quiet waters and appears by reason of its powers of rapid movement to be able to avoid, in large part at least, being drawn into the swifter currents. Some laboratory tests of the possible speed of locomotion of these small organisms showed for 13 specimens an average speed of 1.2 inches per second. Pollutional forms were noticeably more prevalent at this point than above the city, although their actual numbers were small, a fact to be considered in connection with the very brief time of passage to this station from the actual points of discharge of the city wastes.

Bottom deposits.—Eighty-seven samples of bottom deposits were taken at station 598 during the period September, 1914, to December, 1915. Of these, 69 were of mud, 14 of sand with traces of mud, and 4 of clean gravel or pebbles only.

At this station also, as at 475, the presence or absence of mud on the stream bed is essentially a function of water movements. The mud accumulates when conditions of stream flow are stable; it is partially or entirely swept away by floods, and again accumulated with the return and continuance of hydrographic stability.

The prevailing type of sample from this station is characterized by light or yellowish color, little or no odor, and rather granular con-

sistency, indicating the presence of a relatively small amount of organic matter.

A few samples, however, show some of the conditions associated with pollution. Seventeen of the 69 samples contained an average of 28 tubificid worms (*Limnodrilus*) and 6 young bivalves per sample. The corresponding numbers of these organisms usually associated with pollution averaged considerably greater at station 475, namely, 81 worms and 23 bivalves per sample. This was true of 51 of the 60 samples which contained mud, as compared with the much smaller ratio of 17 out of 69 mud samples at station 598.

Such other pollutional forms as *Chætogaster*, *Æolosoma*, and mats of *Anthophysa* appeared frequently in the samples from 475, but never in those from 598.

Forty-three samples from this station showed pollutional organisms in moderate or small numbers and organisms of cleaner habitat in large numbers, thus indicating the presence of organic matter in moderate amount. Seven samples contained chiefly those organisms that are not associated with pollution.

Out of 35 bottom samples collected at station 619, only 4 contained mud, the current at this point being strong enough during most of the year to prevent deposit of suspended matter and silt. Three of these samples contained pollutional organisms in sufficient numbers to indicate presence of organic matter in large amount. The fourth showed moderate pollution only.

TABLE No. 5.—*Physical and biological status of bottom sediments from stations Nos. 475 and 598.*

Station.	Number of samples.	Time included.	Color.		Odor.		Consistency.		Pollutional organisms.		Summary—Average number.	
			Dark to black.	Light or yellowish.	Offensive or stagnant.	Slight, not offensive.	Soft, sticky, and slimy.	Somewhat soft, granular, or tough.	Abundant.	Moderate number or few.	Showing strong pollution.	Showing moderate and light pollution.
475	47	July, 1914, to December, 1915	39	8	42	5	37	10	39	8	39	8
598	60	do	25	35	13	47	18	42	15	45	18	42

SUMMARY OF BIOLOGICAL CONDITIONS IN THE LOUISVILLE DISTRICT.

In flowing the 108 miles from Cincinnati to Louisville the water of the Ohio is retarded by slow movement through a long pool whose lower end is at Louisville. This pool is a factor of importance because of its impounding action, resulting in a time period sufficiently long, during low water, to permit decomposition of organic matter to such a degree that crustacea find here ample food supply and quiet envi-

ronment. These organisms multiply accordingly. Their presence in numbers is significant of the completion of the earlier stages in the process of reducing sewage or other waste matter to a condition of comparative stability and reasonable safety from a sanitary point of view.

Bottom samples confirm, in general, the evidence of plankton samples to the effect that organic matter, though present, is not especially abundant, and that the first stages of decomposition have been completed.

This water, of fairly good quality, now receives contaminating material from Louisville. Pollutional organisms have developed only in small numbers when station 619 is reached. Mud samples, however, show the presence of organisms associated with pollution.

THE PADUCAH DISTRICT.

The river at Paducah is approximately nine times as great in volume as at Pittsburgh. During the flow of 320 miles from the last point of considerable contamination, Louisville, four rivers, the Green, the Cumberland, the Wabash, and the Tennessee, have contributed their waters. Two of these streams, the Wabash and the Tennessee, are of large size. These tributaries have no record of recent pollution. The main stream itself receives direct contamination only from Evansville, Ind., with 70,000 population, 130 miles above Paducah, but in the large volume of water the sewage thus received is negligible. This lower portion of the Ohio watershed is but thinly populated, as a rule. Finally, the sewage from the small city of Paducah (24,000) adds no appreciable burden to the river.

Samples were collected at station 904, above the mouths of the Tennessee and the Cumberland, at the mouths of each of the rivers, at station 920 opposite Paducah, and at stations 926 and 933 below the city. The studies at these points were confined to the months of September and October, 1914. The results are summarized in Table No. 6 and the more important facts are shown graphically in planktograph No. 13.

At all stations moderately high turbidity prevailed and levels were somewhat unstable during September. These conditions were improved in October.

Plankton at all stations was small in amount at all times. September samples yielded a very scant plankton, but decided increase was the rule in October samples, except in the Tennessee River and the main stream station which it immediately influences.

The biological balance of organisms is noticeable at all main stream stations, especially at station 933. This condition is best developed in October. Organisms associated with pollution were sparingly present or were absent altogether. This speaks well for the status

of the water as it proceeds on its way from the Paducah district. The balanced and uniform distribution of organisms is a sort of biological democracy wherein competition for food is brisk and aggressive, but no member of the community of organisms is sufficiently powerful or numerous to accomplish the extinction of other classes and to overthrow the existing mutual adjustment of aquatic life. Such a condition of balance has uniformly been noted in those sections of the river in which biological self-purification of the water has proceeded nearly to completion and is perhaps the best evidence of the prevalence of natural conditions and of the absence of toxic wastes or of other abnormal and destructive agency.

Six samples of bottom sediment, two of which consisted of clean sand, were taken at station 904 during September and October, 1914.

Two samples contained young mussels in small numbers. These organisms are so persistently found under conditions of heavy pollution that their place seems to be with, or very near, the pollutional organisms, particularly when they occur in large numbers.

Four samples of deposits taken in September and October, 1914, well up the mouth of the Cumberland River, contained organisms of indefinite habitat, and two samples taken at station 920 in September, 1914, gave similar indications.

Five samples taken well up the mouth of the Tennessee River during September and October, 1914, showed small numbers of tubificid worms, and young mussels appeared in three. Organisms of doubtful significance were found in small numbers in the others.

Five bottom samples were taken at station 933 during September and October, 1914. Organisms were few except in one sample, which yielded larvæ of *Chironomus* and of May fly.

SUMMARY OF BIOLOGICAL CONDITIONS IN THE PADUCAH DISTRICT.

The decreased yield of plankton in the Paducah district is evidently due to the small amount of organic matter present and to dilution by tributaries.

Scarcity of the organic matter which serves as food supply, either direct or indirect, for most plankton organisms may be credited to a number of factors which combine to produce this result. The water on leaving the Louisville district did not contain a great amount of waste, for, notwithstanding the considerable quantity contributed here, the volume of water is so great that the relative contamination is small when compared to that at Pittsburgh. By the time the water arrives in the Paducah district its volume has been further increased by tributaries and only an inconsiderable amount of additional waste has been received. Meantime the various purification agencies, biological as well as chemical and physical, have

reduced much of the organic matter, leaving cant food supply for the diminishing plankton.

Dilution by tributaries is also a factor. Those tributaries from which data are available tend to dilute, instead of to concentrate, the plankton of the main stream. This means that conditions of contamination and of subsequent purification are so related in these tributaries as to result in a lower plankton content in the tributary than in the main stream.

GENERAL SUMMARY OF BIOLOGICAL INVESTIGATIONS.

The outstanding charateristics of the Ohio River which definitely influence its biological content are mainly as follows:

The Ohio constitutes a kind of natural "Mason and Dixon's line." Tributaries from the north are affected by rigorous winter conditions, and the spring thaw unloads in their waters large amounts of organic matter which have accumulated during the colder weather. Tributaries from the south experience much milder winter conditions. The streams are not icebound, as a rule, and the contained organic matter is disposed of by purification processes which, on account of the higher temperatures, may proceed to advantage from the time the sewage or other waste enters the water. Such a tributary brings to the main stream a water whose organic matter has been disposed of to a degree which is impossible for the cold waters of the northern tributary.

The adjustment of these differences by the mingling of the waters in the main stream produces situations which are biologically important because of the continuous variation in amount, kind, and degree of decomposition of the food supply thus brought by these tributaries.

Geologically speaking, the river is young. It has not yet reached grade, and consequently a large amount of erosion is taking place. This expresses itself in the frequent and high turbidity, which in turn becomes a factor of much significance to holophytic (plantlike) organisms by depriving them of sunlight and checking their growth. These minute plants constitute much of the food supply of certain animals of the plankton. Moreover, these plants produce oxygen in the water by photosynthesis.

The presence of many riffles, pools, bars, and islands constitutes an effective mixing apparatus which hastens the adjustment of differences that are imposed anew by each tributary, or sewered town, or drainage from industrial establishments. Continuous variation of speed, of depth, and of relative surface exposure is experienced by the moving water. Aquatic organisms requiring different degrees of water movement, of light, or of concentration of organic matter thus find conditions to their liking, and the biological expression of these various conditions is seen in the great diversity of plants and animals which constitute the Ohio River plankton.

High floods occur in spring, and frequently at other seasons. Currents are swift and the water speedily traverses the length of the river. During a relatively dry period the water is quite low and seems almost motionless in the larger pools. These extreme fluctuations cause enormous variations in the time of flow, with resulting disaster or advantage to most plankton and mud organisms which, as a rule, flourish in proportion to the degree of stability and quiet in their environment.

Numerous dams serve to impound and conserve water during dry weather and to increase the volume of water for the reception of sewage or other waste. The time-factor is thus increased also, to the advantage of plankton organisms in the matter of breeding and in the better decomposition of organic matter which provides food for these organisms.

Organic matter of many kinds, introduced mainly in the regions of Pittsburgh, Cincinnati, and Louisville, constitutes the chief reason for the existence of most of the Ohio River plankton and certain of the mud organisms as well, which find abundant food and favorable environment in the conditions thus created near the main points of pollution. Smaller amounts of polluting material introduced at various other points serve to reproduce to some degree the conditions which encourage plankton life on a large scale at the three places of heavy pollution.

An abnormal condition of the water, such as the acidity of the Monongahela River, is reflected by an abnormal condition of the plankton and aquatic life in general. The apparent effect on the aquatic organisms is the killing off of certain of them, either by first removing their food supply of bacteria, as in the case of many ciliates, or by direct unfavorable action of the acid on the cell contents of the organisms concerned. The aquatic life surviving such abnormal state of the water is limited to comparatively few varieties, although these may be present in large numbers, as in the Monongahela.

Conversely, the persistent yield of an abnormal plankton may be regarded as evidence of the continuous operation of some unusual factor in the local environment.

Each tributary or stream is a law unto itself, because it has its own peculiarities of stream flow, degree of contamination, temperature conditions, and other controlling factors. Nevertheless, within broad limits, many streams are much alike, and the biological reflections of their predominating characteristics are comparable. The most important items in such comparisons are food supply of sewage and other organic matter, adequate time for breeding of organisms and decomposition of organic matter, and absence of toxic waste or other unduly destructive conditions, the latter including persistent turbidity, which deprives holophytic organisms of light and prevents their activity.

As each separate stream has its own characteristics, so the various portions of any one stream may present a series of conditions which are to some degree related to and yet distinguished from one another. A typical series of differing biological situations is presented by the Ohio and its tributaries. The aquatic organisms respond to the dominating factors, as is shown by the heavy plankton yield restricted to very few kinds of organisms in the Monongahela, the net result of abundant and suitable food, and of presence of acidity which kills off certain forms. The uniform and natural distribution of organisms in the Wheeling district is evidence of the successful elimination of the unfavorable conditions. Predominance just below Pittsburgh, Cincinnati, and Louisville of typical organisms usually associated with sewage pollution is the biological reply to the discharge of sewage from those cities. Similarly, the light yield of plankton at Portsmouth, at station 461, and finally at station 933, the erratic yield of the Licking, the well-balanced plankton of the Beaver, and of the Ohio at certain places, notably at stations 598 and 933; all these are the biological expression of the various interrelated factors that prevail at the respective locations.

The aquatic life at any given sampling station also varies with respect to season and temperature, rainfall, and amount of sunlight. Most of the species of organisms are active only during moderately warm weather. However, if conditions are stable and water is clear enough to admit sunlight, a heavy plankton, principally of diatoms and other minute algæ, is the usual result, even if the temperature is low. This is shown by the high content of diatoms at successive Ohio River stations in November, 1914. A similar pulse of the same organism occurred in November, 1915, and in latter part of August and first part of September in 1916.

Flood conditions obscure the influence of local environment of the plankton, bring organisms from distant points, interrupt favorable conditions of quiet for the local plankton, and cause turbidity which deprives holophytic organisms of sunlight. Bottom organisms are brought into undue prominence, and clear-water forms, such as crustacea, are carried away or dragged to the bottom by silt deposited on their appendages. Flood-time plankton is essentially misleading as to local conditions, and is therefore of questionable value as an index of the biological conditions prevailing at the station in question.

Bottom sediments represent an accumulation of matter, previously suspended in the water. Such deposits constitute an index as to the condition of the water, unless floods or current remove these sediments too often to permit the development of such physical conditions and biological content as will faithfully reflect the local environment. In these respects the bottom deposits fluctuate more slowly and less widely than does the overlying water. As a rule the results of exam-

ination of sediments are correlated with the results of plankton examination, and the careful inspection of such deposits is accordingly of importance in the biological survey of a stream.

Biological balance as seen in the Ohio River means the presence of organisms in such number and in such assorted varieties as will successfully cooperate with existing chemical and physical conditions in the effective reduction of the organic matter which may enter the water and in carrying on the continuous flux of this matter from the lowest forms of life to the highest. This includes the work of bacteria, of plankton, and of larger organisms. The presence of organic matter such as sewage results in abundance of animal forms rather than plants (aside from bacteria), while dissolved inorganic matter resulting from advanced decomposition favors the presence of plants as the dominating organisms. The middle ground between these two extremes is characterized by presence of a great variety of both animal and plant forms.

Information concerning the history, present condition, and rate and direction of change of a natural water may be obtained from the results of suitable chemical and bacteriological tests. This information is obtainable from such tests only because of extensive preceding studies, during the course of which correlations have been established and methods of procedure have been modified and adapted to secure reliable information with the minimum of possible error of interpretation. The great majority of these investigations have not, however, included an examination of the plankton and related organisms, nor have the tabulated results accredited anything to the activity of these biological workmen. Inasmuch as these organisms are present (and sometimes very numerous) in practically every natural water, it would seem that an adequate examination of this water must include a study of this ever-present biological factor, for otherwise certain phases of the final interpretation will be open to question. It seems reasonable that correlations should exist between this aquatic life and the degree of pollution and extent of self-purification of the water concerned, similar to the correlations which appear when the bacterial content and chemical condition of such waters are studied. To discover and record these correlations is the first task of the biologists who would continue the investigations begun by Forbes, Kofoid, Haeckel, Marsson, Kolkwitz, Eyferth, and others. To determine by long-continued observation and special laboratory tests to what extent and in what ways this biological factor may affect the bacteriological and chemical conditions, and be in turn affected by them, and the manner in which all these factors, together with the physical features, are mutually related in the process of self-purification of streams is the next group of problems awaiting solution.

TABLE NO. 6.—*Microscopical examination (average results).*

Station.	Number of samples.	Temperature (C.).	Turbidity (p. p. m.).	Gage height (feet).	Organisms and other matter (standard units per c. c.).									Volumetric data (c. c. per cubic meter).	
					Holophytic.[1]			Holozoic.[1]						Total plankton.	Amorphous matter and silt.	Total catch.	Plankton.[2]
					Diatoms.	Algæ.	Mastigophora.	Fungi.	Rhizopoda.	Ciliata.	Rotifera.	Crustacea.	Vermes, etc.				
PITTSBURGH DISTRICT.																	
August–October, 1914.																	
M–12	10	22	5.8	6	3				27+a	5	648 ab		5 a	701	10,970	70.65	4.2
A–7	10	18.5	23.8	1.8	89 a	20 a	14	2	34 ab	2	19 a	2	7	129	16,085	133.7	.9
O–3	10	21	15.6	6	8 a	15 b	+	4	6	47 a	504 ab	16	15	615	7,313	54.5	4.2
O–28	10	21	11.2	6	56 a	18 c	7			10	263 ab	122 a		474	8,420	46.25	2.6
Beaver River	10	19.5	16	4.4	329 bc	50 c	61 ab		14	8	119 c	14 a	5	601	6,080	61.9	3.2
WHEELING DISTRICT.																	
August–October, 1914.																	
65	9	20	5.3	8.1	130 bde	16 bc	31 b			3	48 c	69 a	1	298	6,449	39.15	1.8
77	8	21	29.9	7.7	151 ba	10 d	38 bc			5	64 cd	140 ab	+	408	6,644	68.6	3
88	4	19	31	7.9	122 bcd	11 bc	73 bc		+	12	72 ce	89 ac		382	8,350	80	2.3
97	10	20	15	8.2	111 ba	7 bc	44 bc		2	3	97 ace	147 acb		412	7,050	54.25	2.9
PORTSMOUTH DISTRICT.																	
August–October, 1914.																	
340	7	20.7	30	3.3	57 ba	10 bc	5		7 a	14 b				93	12,371	64.6	.5
Scioto River	7	21	60	—.2	79 b	74 bce	2		2	5 b	21 c			190	16,971	108	1.3
358	7	21	45	3.2	51 b	17 bc	2		17 a	7 b	1		5	100	11,912	66.8	.5

[1] Predominating genera are indicated in the respective columns by letters, and are referred to the following key:
Diatoms.—(a) Synedra sp., (b) S. delicatissima, (c) S. biceps, (d) Nitzschia closterium, (e) Asterionella, (f) S. ulna, (g) Navicula, (h) Fragilaria, (j) Nitzschia sigmoidea, (k) Meloisira.
Algæ.—(a) Conferva, (b) Scenedesmus, (c) Pediastrum, (d) Raphidium, (e) Oscillatoria, (f) Ulothrix, (g) Eudorina, (h) Vaucheria, (j) Protococcus.
Mastigophora.—(a) Phacus, (b) Dinobryon, (c) Euglena, (d) Trachelomonas, (e) Anthophysa, (f) Chlamydomonas.
Rhizopoda.—(a) Difflugia, (b) Arcella, (c) Actinophrys.
Ciliata.—(a) Vorticella, (b) Codonella, (c) Carchesium, (d) Tintinnus, (e) Paramecium, (f) Amphileptus, (g) Stylonchia, (h) Epistylis, (j) Opercularia.
Rotifera.—(a) Brachionus, (b) Rotifer vulgaris, (c) Anuræa cochlearis, (d) Distyla, (e) Polyarthra, (f) Synchæta.
Crustacea.—(a) Cyclops, (b) Bosmina, (c) Chydorus, (d) Daphnia.
Vermes, etc.—(a) Nematode, (b) Chironomus larvæ, (c) Macrobiotus.
[2] Computed from standard unit volumes. (See p. 17.)

TABLE No. 6.—*Microscopical examination (average results)*—Continued.

Station.	Number of samples.	Temperature (C.).	Turbidity (p. p. m.).	Gage height (feet).	Organisms and other matter (standard units per c. c.).											Volumetric data (c. c. per cubic meter).	
					Holophytic.			Holozoic.						Total plankton.	Amorphous matter and silt.		
					Diatoms.	Algæ.	Mastigophora.	Fungi.	Rhizopoda.	Ciliata.	Rotifera.	Crustacea.	Vermes, etc.			Total catch.	Plankton.
CINCINNATI DISTRICT.																	
August–October, 1914.																	
661	8	20.7	115		149 be	56 cse	3		8	10 b	11 c		1	239	17,108	135	1.8
Little Miami River	6		40	6.1	34 bf	69 abc	14 d		8	18 c	40 ba		12	194	20,909	95.7	.87
Licking River	6	22	140	1.7	3	24 g	32 ce		29 a	9 h	63 b	6	1	165	20,817	60	.33
678	10	20.5	227	6.2	51 be	41 cb	31	+	3	45 bch	66 ac	8	26	261	20,633	66.2	.97
Miami River	8	18	67	2.2	41 ag	93 abc	15 cf	2	2	15 db		28 a	15 a	225	20,340	102	.60
662	6	19	77.5	6.1	34 b	38 ca	7		2	20 bc	19 ca	18 a	1	143	16,625	85.75	1.36
November, 1914–January, 1915.																	
661	12	5.4	44	17.6	396 bce	15 be	27 b			17 c	22 cf			675	80,120	172.6	2.4
Little Miami River	11		190	8	216 fegh	17 ae	3						12 a	264	80,308	221.5	.71
Licking River	10	7	166	48	66 a	15 ae	14 e	+	4 a	1	8		28 ab	186	171,080	309	.37
675	14	4	190	17.3	479 bce	168 ce	30 e	1	8 b	8 ac	15 a		12 a	630	208,232	430.5	2.93
Miami River	6	1	27	3.7	79 a	10 e	5			7	25 c		3	130	57,702	172.5	.42
662	13	5	210	17.7	532 bfc	60 ce	31 e	+		16 b	20		83 a	732	114,167	439	10.65
February–March, 1915.																	
661	8	4			44 c	5	1										
Little Miami River	8	4	62	5.9	20 cj	10 e	2	6	7 a	4	10		27 a	105	49,987	191	.39
Licking River	9		154	8.4	10 ac	5 h	1		14 a	8 ba	24 b		18 a	93	32,002	172.5	.47
673	9	4	139	261	25 a	3		1	4 a	2	3		22 a	58	28,520	172.5	.21
Miami River	9	5	31	5.3	63 a	6	1	1	4	3 a	11 bd	9 a	38 a	94	81,623	175.8	.22
662	9	3.5	103	27.9	31 aj	13 e		2	8 a	19 bcj	1		28 ac	100	103,044	200	.48
								3	15 a	11	6	2	29 a	103	102,900	270.5	.36
April–May, 1915.																	
661	8	15.5	24		502 ef	5 c	20 he		6	11 ba	42 ca		1	617	35,363	102.6	1.64
Little Miami River	7	17		6.2	300 fbj	39 ced	76 fd		7 e	29 fg	80 ba		6	573	16,286	81.7	2.8
Licking River	7		154	3.1	79 fa	40 gc	80 f			6	14 b		28 a	384	111,000	211	1.01
675	7	18	55	12	219 bce	14 ca	9 ef	3	4	4	17 ab	7 c	14	368	17,614	62.2	1.36
Miami River	8	16	20		1,143 foe	207 cbj	33 fo	6	6	13 a	110 baf	10 a	24 ac	1,561	43,962	116.2	6.72
662	8	15	119	12.6	469 cbe	46 ec	14		20 a	40 hb	80 ac	8	18	656	104,180	187	.18

June–July, 1915.																		
461	10	22			31 f	23 aef	7 e	2	29 ae	33 bf	15 c		37 a	194	319,286	623	.46	
475	9	28	401	16	22 k	29 eg	25 ac	2	13 ab	65 bda	11	5	21 a	213	223,022	563	.46	
Miami River	5				5	19 b	3		32 a	41 b	18 c	1	20 a	180	200,200	767	.60	
482	9	22	866	17.3	17 k	19 c	14 e	3	19 a	30 ab	34 c		18	144	223,311	888	.62	
LOUISVILLE DISTRICT.																		
September–October, 1914.																		
366	9	21	71	5.4	21 b	66 a	1		+	36 b	100 ca	75 a	19	210	6,459	30.7	2.36	
619	17	30	60	5.2	28 b	68 ac	49	2	3	26 b	44 c	3	7	202	9,952	884	1.48	
November, 1914–January, 1915.																		
366	14	3	230	16.1	422 bcj	26 ab	22 e	4	29 a	161 b	55 bcd	2	21 a	734	171,402	548.5	3.76	
619	24	19	25	16.5	464 bea	34 ac	66 de	+	44 a	10 b	23 ab	3	11 a	628	167,689	450	2.52	
February–March, 1915.																		
366	9	4.3	146	26	21 a	3	12 e		47 a	1	1		26 a	124	146,511	326	.3	
619	16	4	180	23.9	22 a	2	5		25 a	3			28 a	100	77,843	301.5	.42	
April–May, 1915.																		
366	61	5	17	16	175 ae	25 b	18 f	1	2	9 b	17 c		1	343	9,236	44.9	1.21	
619	8	14	22	10	248 bea	22 cad	13		8	12 b	16 a		9	339	11,485	52.5	1.44	
June–July, 1915.																		
366	9	24.5	280	141	7	8	5		44 a	22 b	15 c	6	19 a	125	143,655	324	.68	
PADUCAH DISTRICT.																		
September–October, 1914.																		
904	5	22	100		31 b	60 ac				10 b	60 ca	40 a	1	255	14,700	30.5	.57	
Cumberland River	4	24	190		1	12 e	6		30 a	37 d	22 a	3		101	11,430	41.2	.3	
683	9	23	105		47 ba	41 ab	+		30 a	37 d	94 a	38 ad	+	280	14,322	47.6	1.08	
Tennessee River	6	25	82		10	6	2		8	37 bf	1		3	97	14,030	46.5	.19	
699	4	24	132		32 ak	32 ab	1		12 a	21 b	37 a			134	12,300	37.4	.4	
923	10	23	128		30 b	38 a			10	38 bd	42 a	30 c	4	172	13,839	42.7	.68	

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EXPLANATORY NOTE.

In the planktographs which follow all organisms are expressed in volumetric terms of cubic standard units instead of numbers.

Organisms whose life processes are essentially plantlike are classed as Plants, and are plotted in the upper half of the chart. Similarly, organisms whose life processes are essentially those of an animal are classed as Animals, and are plotted in the lower half of the chart.

Data of tributary streams are inserted in a narrow vertical space which extends across the chart from top to bottom near the point where this tributary enters the main stream. The various plankton forms are here represented by symbols, with the appropriate abbreviation placed near.

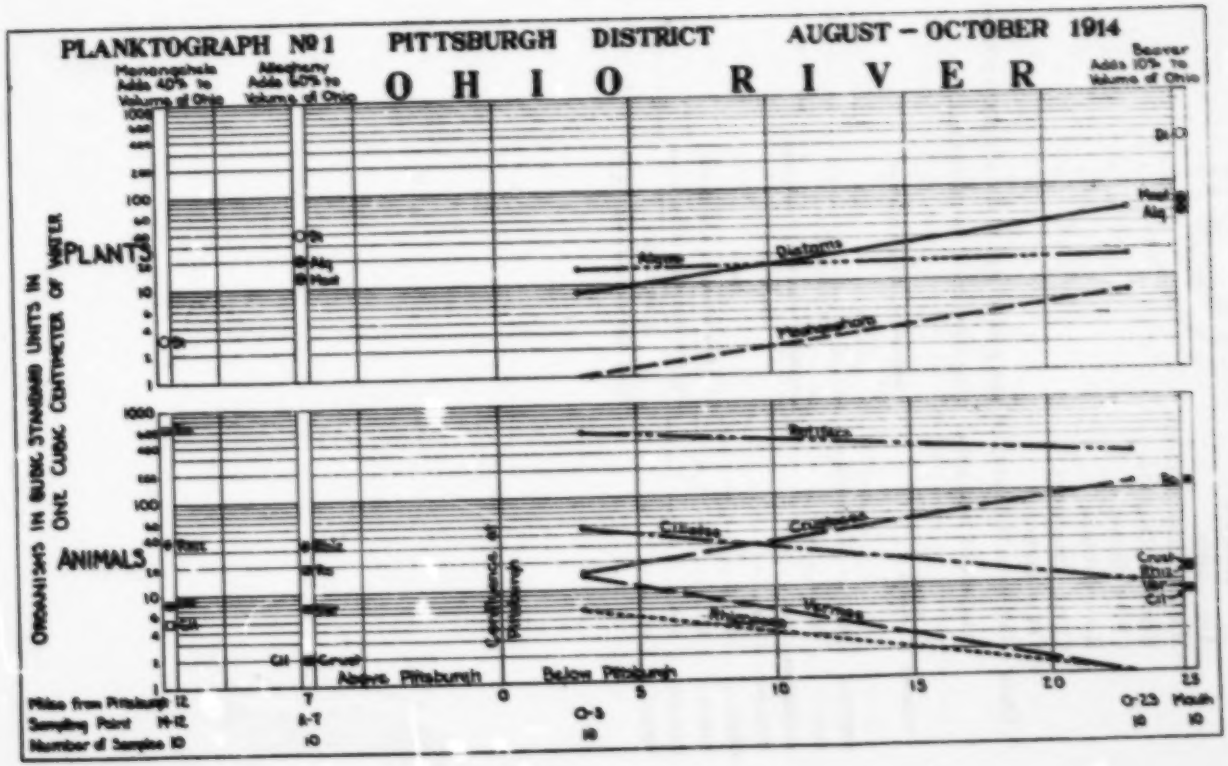
The following abbreviations are used:

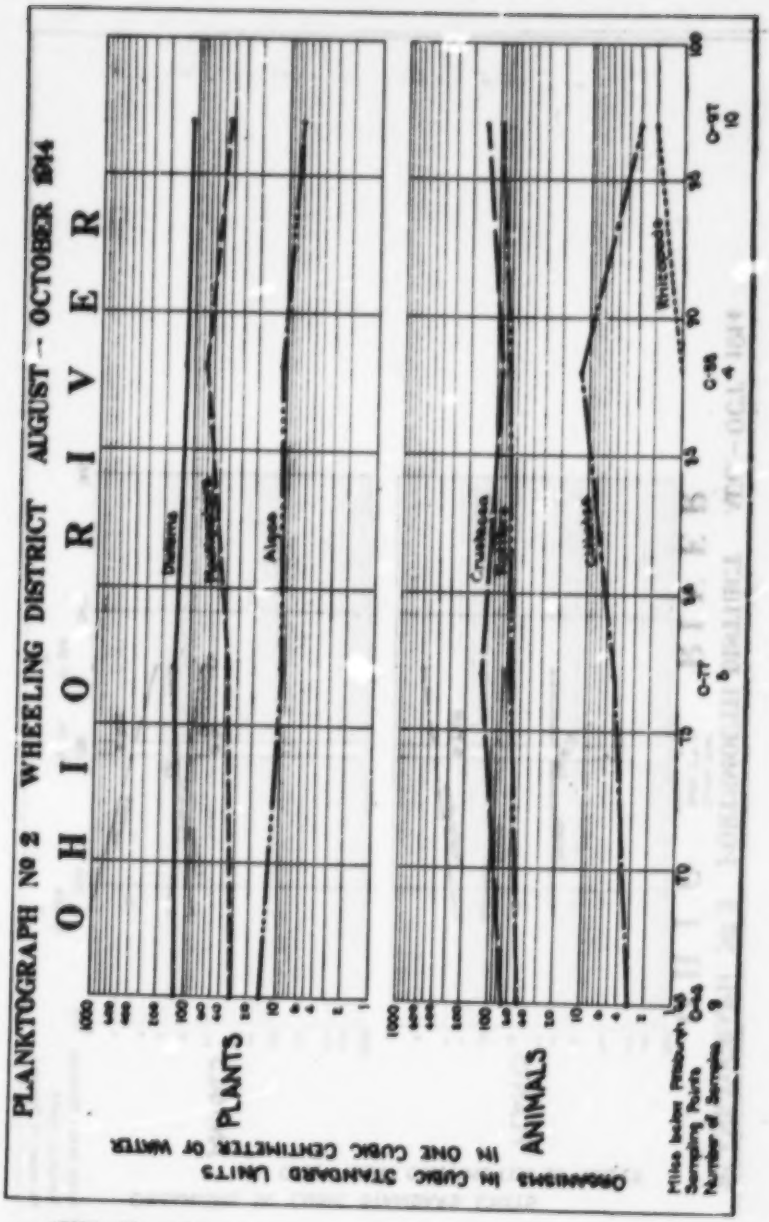
Di.—diatoms.
Alg.—algæ.
Mast.—mastigophora.
Rhiz.—rhizopoda.
Cil.—ciliates.
Ro.—rotifers.
Crus.—crustacea.
Ver.—vermes.

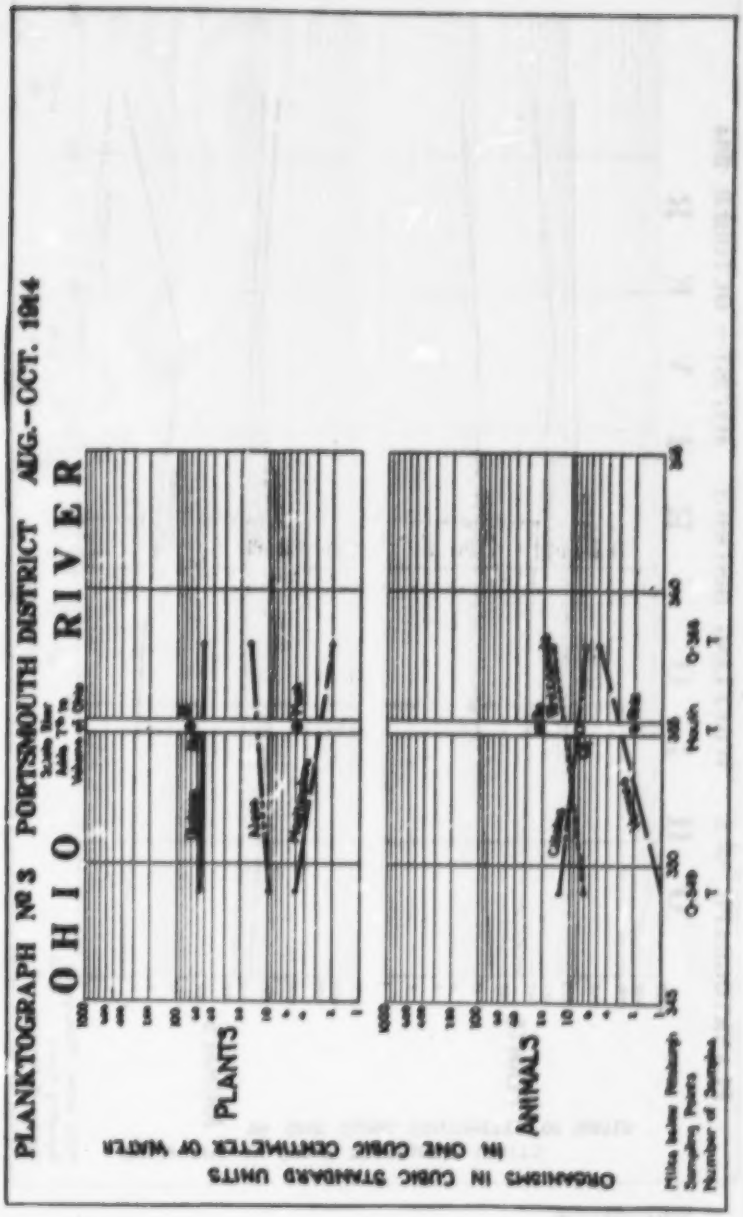
Data relating to the samples are placed below the diagram proper.

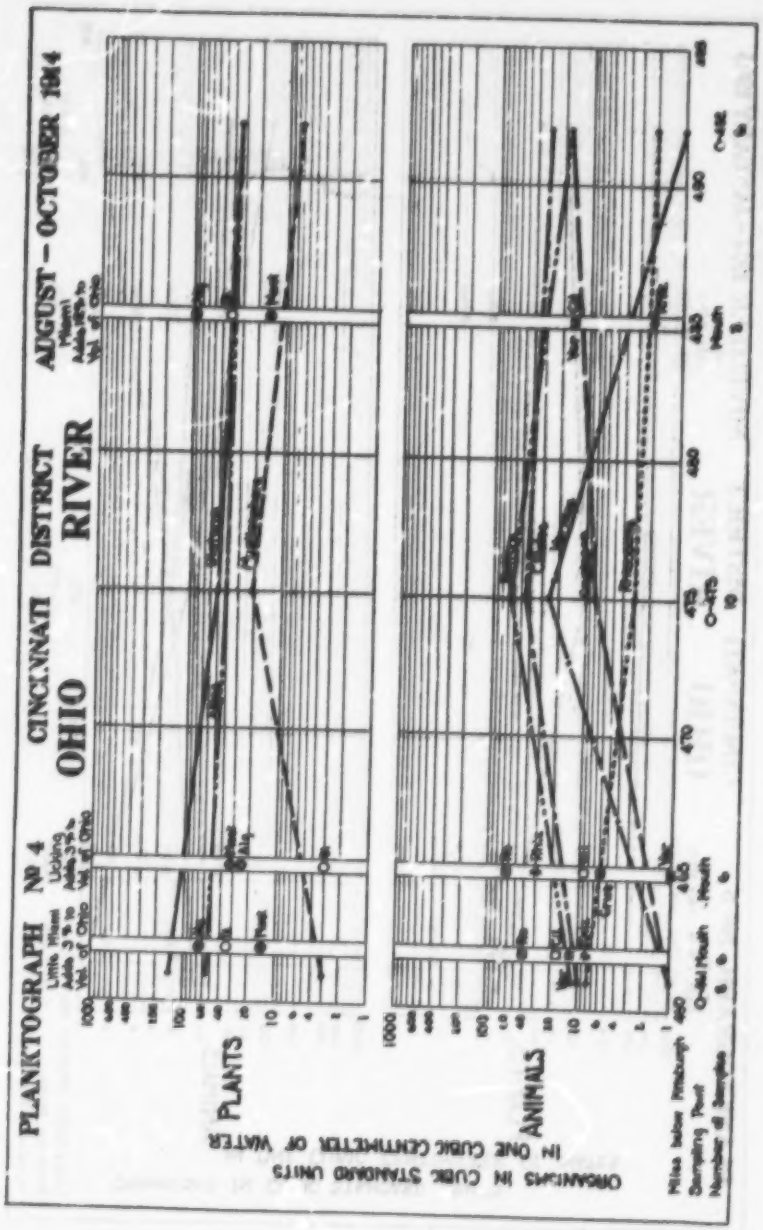
MANNER OF INDICATING ORGANISMS ON PLANKTOGRAPHS.

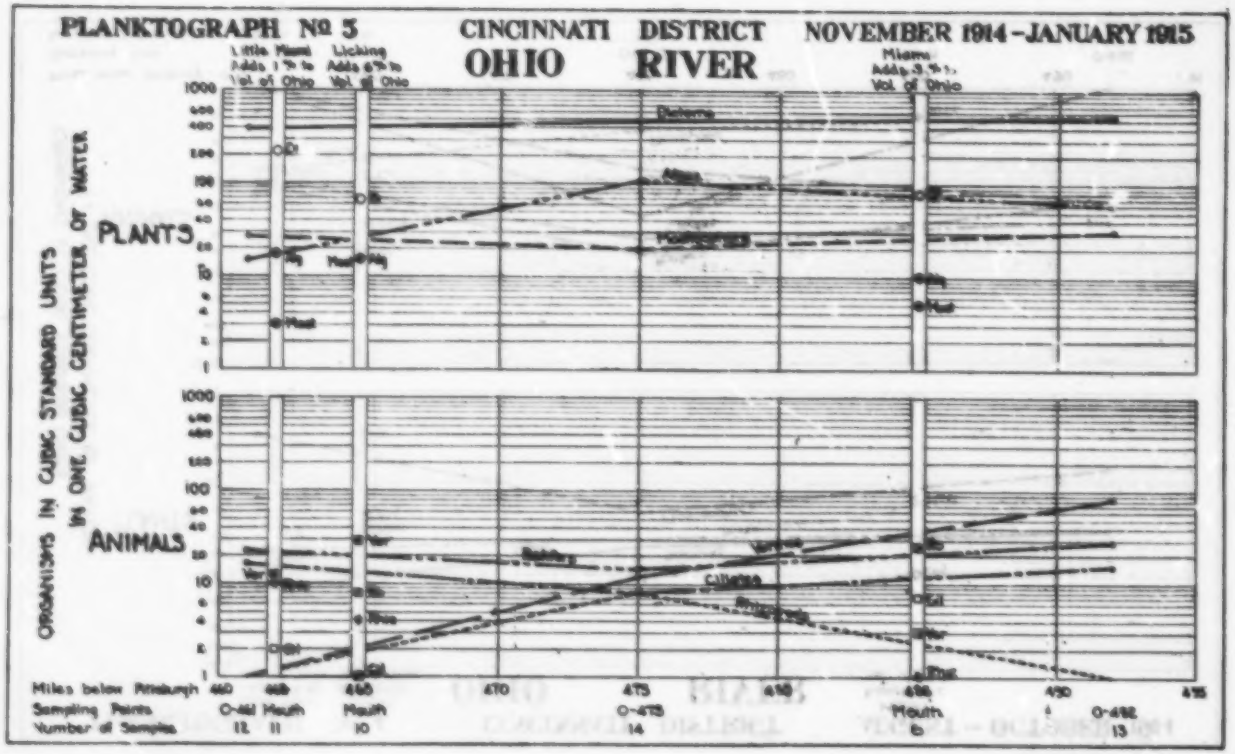
Organism.	Abbreviation used.	Designating mark for organisms.
Diatoms	Di	(Unbroken line.)
Algæ	Alg	(Long dash alternating with three dots.)
Mastigophora	Mast	(Short dashes.)
Rhizopoda	Rhiz	(Dots.)
Ciliata	Cil	(Long dash alternating with one dot.)
Rotifers	Ro	(Long dash alternating with two dots.)
Crustacea	Crus	(Long dashes.)
Vermes	Ver	(Long dash alternating with "x.")

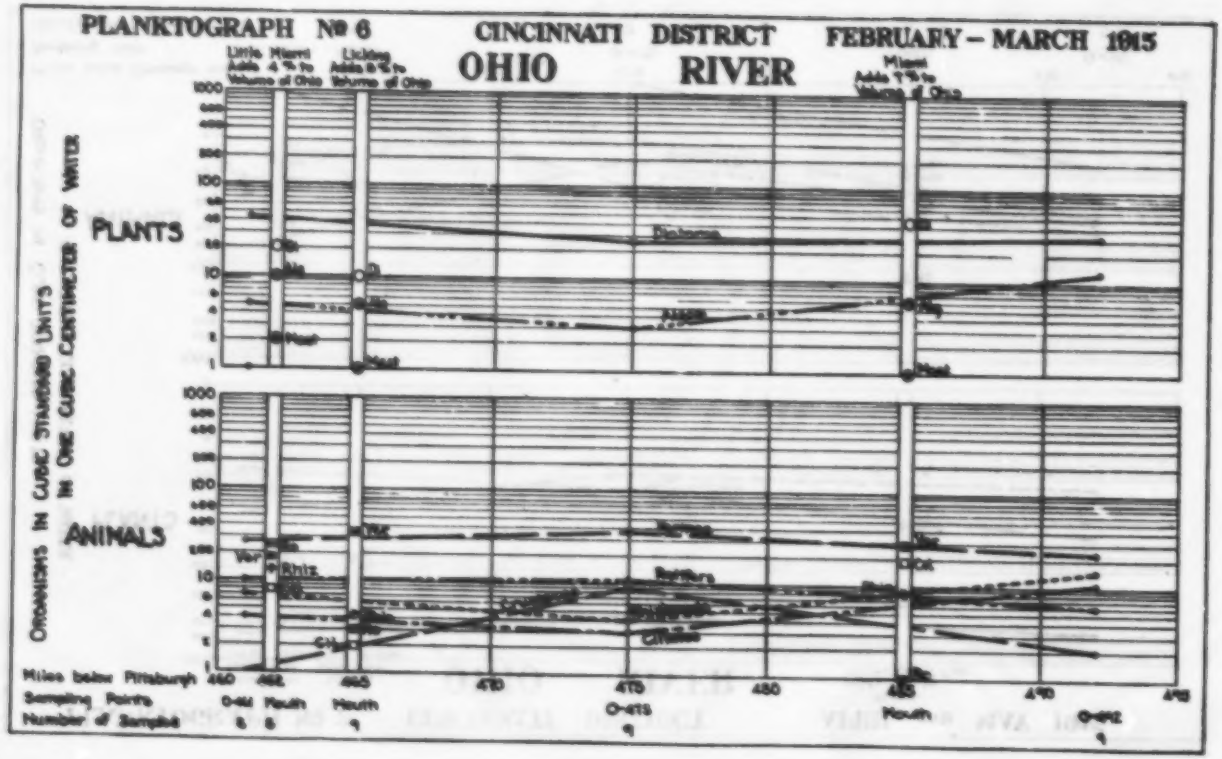

PLANKTOGRAPH Nº 1 PITTSBURGH DISTRICT AUGUST – OCTOBER 1914
O H I O R I V E R
Monongahela Adds 40% to Volume of Ohio
Allegheny Adds 60% to Volume of Ohio
Beaver Adds 10% to Volume of Ohio
ORGANISMS IN BUDIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
PLANTS
ANIMALS
Diatoms
Protozoans
Rotifers
Crustacea
Nauplii
Cyclops
Nematodes
Confluence of Rivers at Pittsburgh
Above Pittsburgh
Below Pittsburgh
Miles from Pittsburgh
Sampling Point
Number of Samples
Mouth

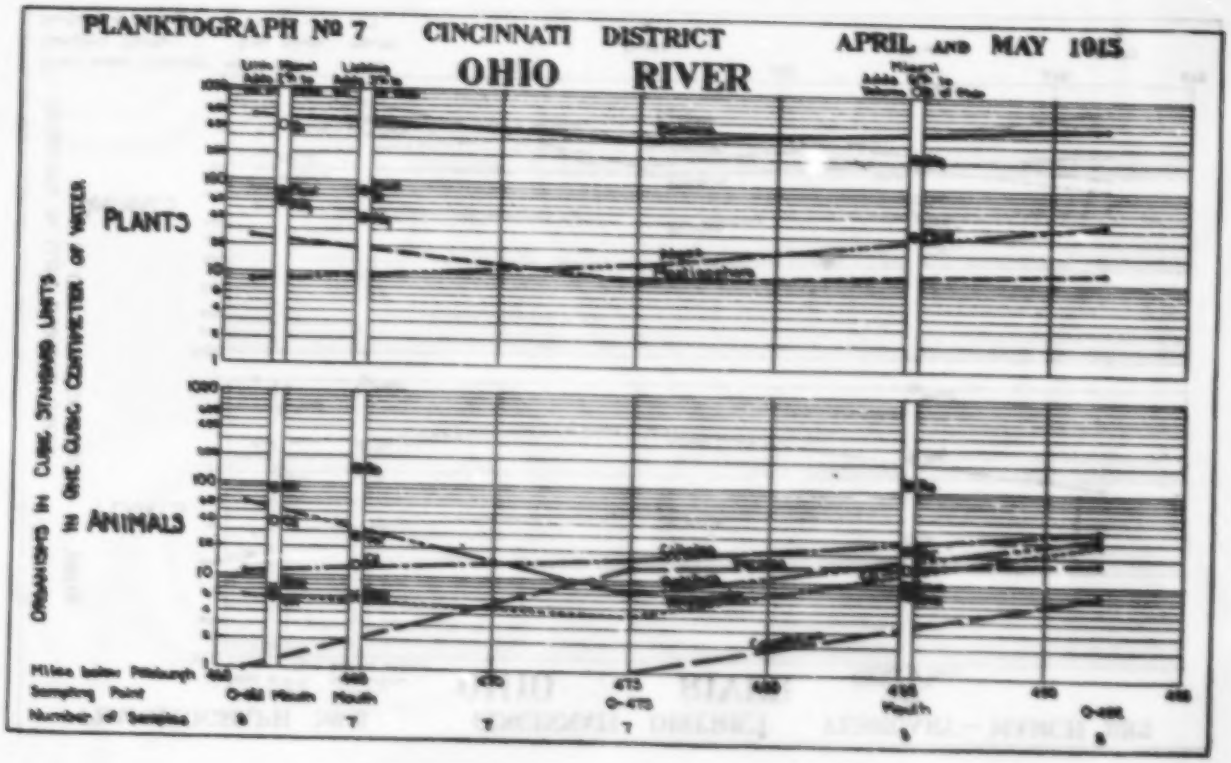

PLANKTOGRAPH № 2 WHEELING DISTRICT AUGUST – OCTOBER 1914
O H I O R I V E R
PLANTS
ANIMALS
Diatoms
Algae
Crustacea
Rotifers
Rhizopods
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
Miles below Pittsburgh
Sampling Points
Number of Samples
0-ST 10
0-ST 5
0-ST 4

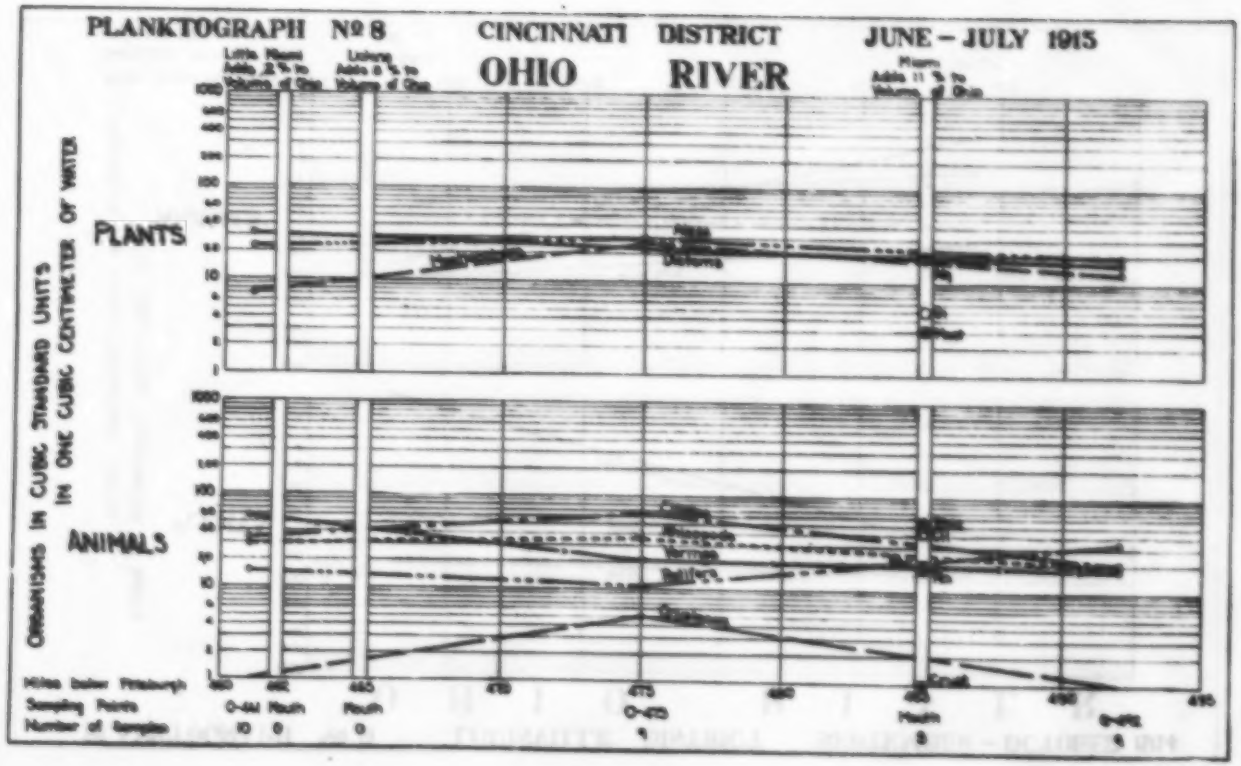

PLANKTOGRAPH № 3 PORTSMOUTH DISTRICT AUG.–OCT. 1914
OHIO RIVER
PLANTS
ANIMALS
ORGANISMS IN CUBIC STANDARD UNITS
IN ONE CUBIC CENTIMETER OF WATER
Miles below Pittsburgh
Sampling Points
Number of Samples

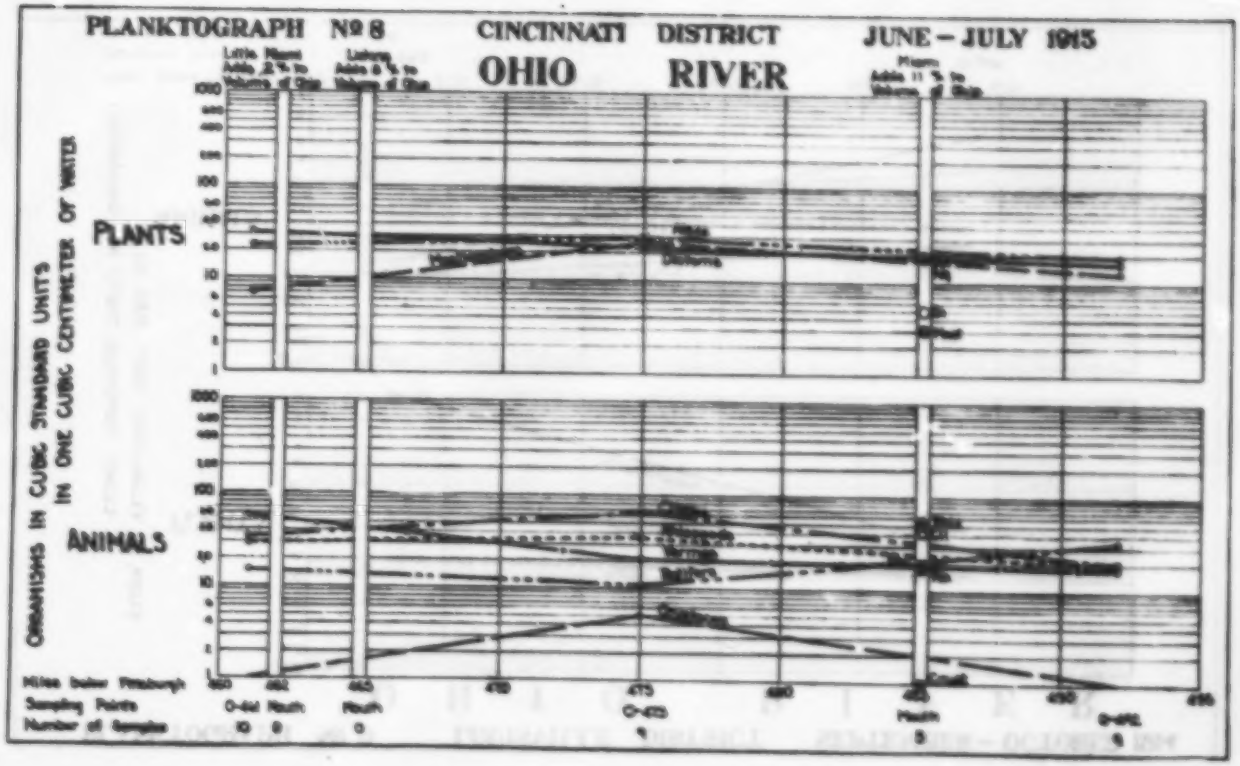

PLANKTOGRAPH № 4 CINCINNATI DISTRICT AUGUST – OCTOBER 1914
OHIO RIVER
PLANTS
ANIMALS
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER

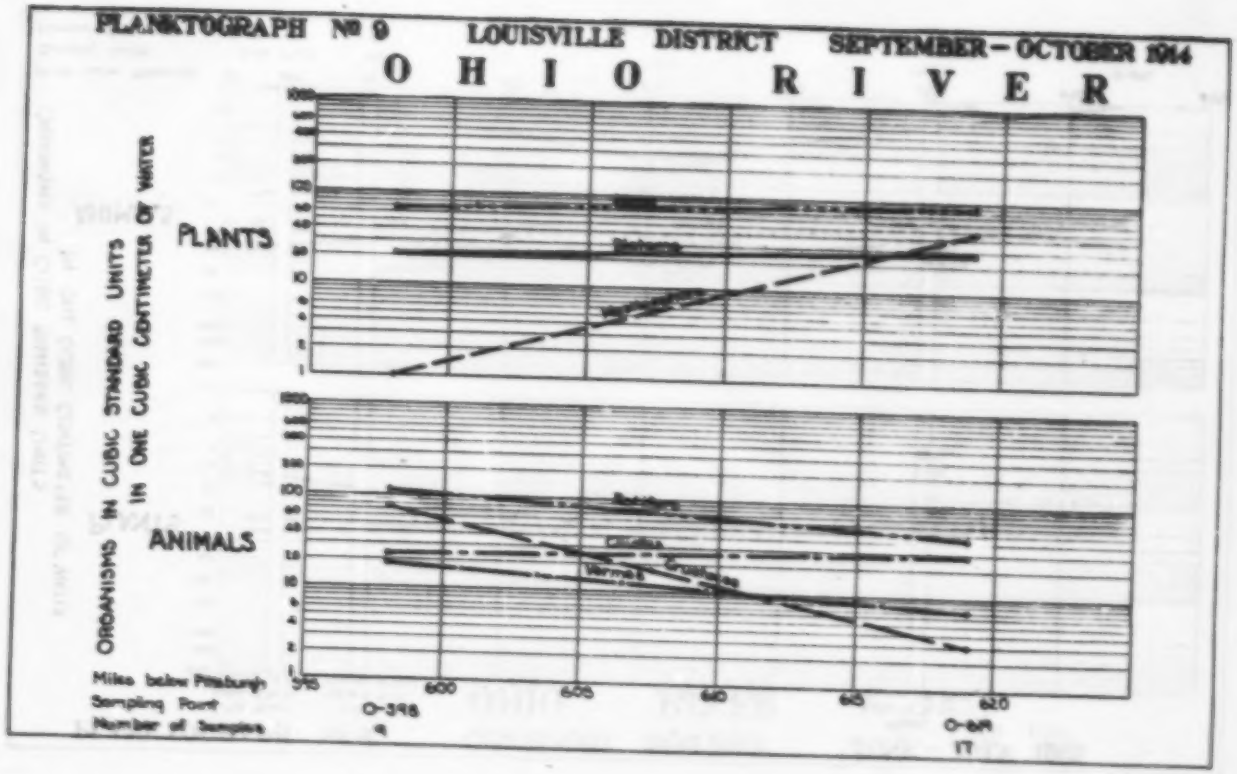

PLANKTOGRAPH No 5
CINCINNATI DISTRICT
OHIO RIVER
NOVEMBER 1914 - JANUARY 1915
Little Miami Adds 1 % to Vol. of Ohio
Licking Adds 6% to Vol. of Ohio
Miami Adds 3 % to Vol. of Ohio
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
PLANTS
ANIMALS
Diatoms
Algae
Protozoa
Rotifers
Cladocera
Copepods
Miles below Pittsburgh
Sampling Points
Number of Samples
460
468
465
470
475
480
485
490
495
0-461
Mouth
Mouth
0-475
Mouth
0-492
12
11
10
14
15
13

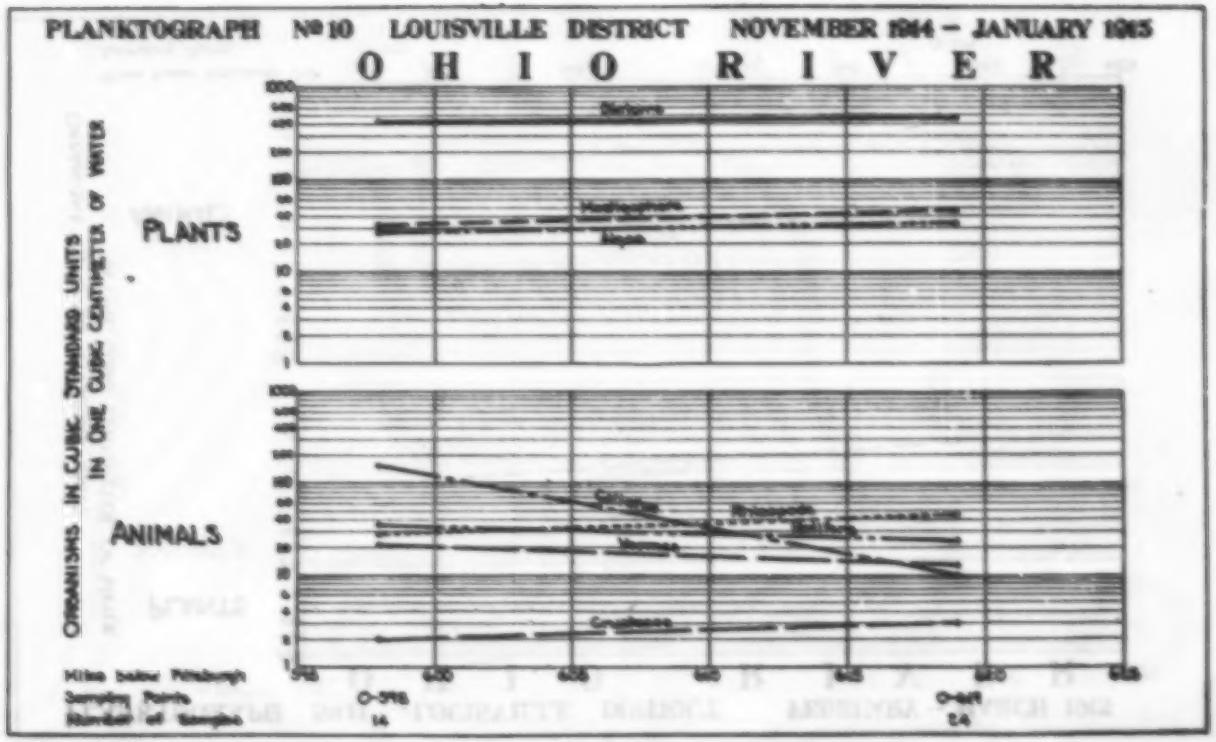

PLANKTOGRAPH № 6
CINCINNATI DISTRICT
FEBRUARY – MARCH 1915
OHIO RIVER
PLANTS
ANIMALS
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
Miles below Pittsburgh
Sampling Points
Number of Samples

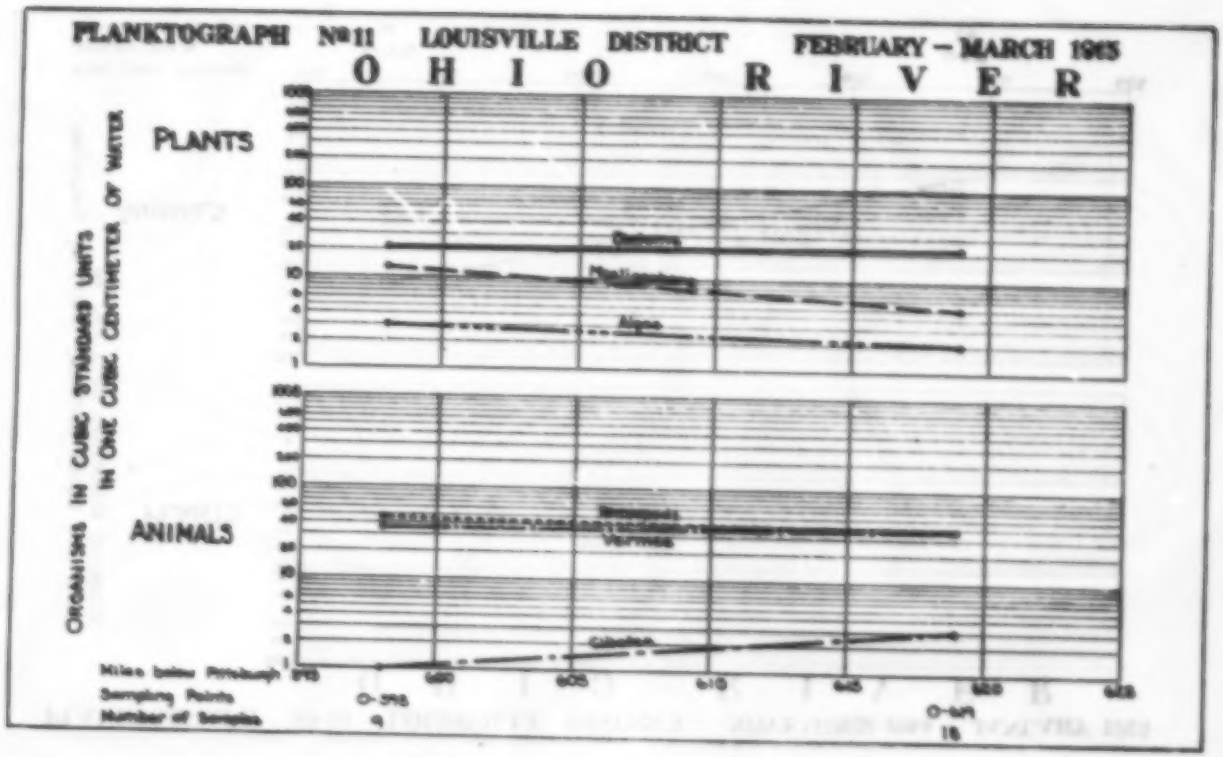

PLANKTOGRAPH Nº 7 CINCINNATI DISTRICT APRIL AND MAY 1915
OHIO RIVER
PLANTS
ANIMALS
ORGANISMS IN CUBIC STANDARD UNITS
IN ONE CUBIC CENTIMETER OF WATER
Miles below Pittsburgh
Sampling Point
Number of Samples
O-462 Mouth Mouth
O-473
Mouth
O-498

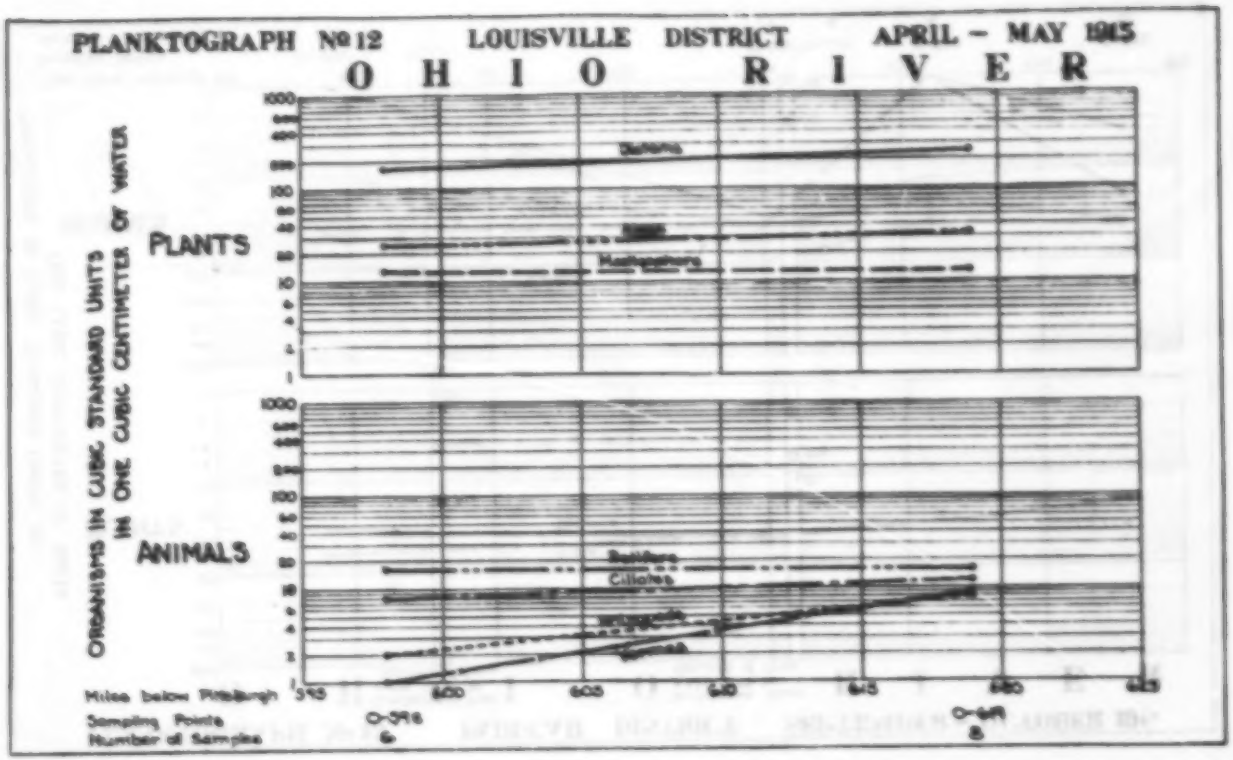

PLANKTOGRAPH Nº 8
CINCINNATI DISTRICT
JUNE – JULY 1915
OHIO RIVER
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
PLANTS
ANIMALS
Miles Below Pittsburgh
Sampling Points
Number of Samples

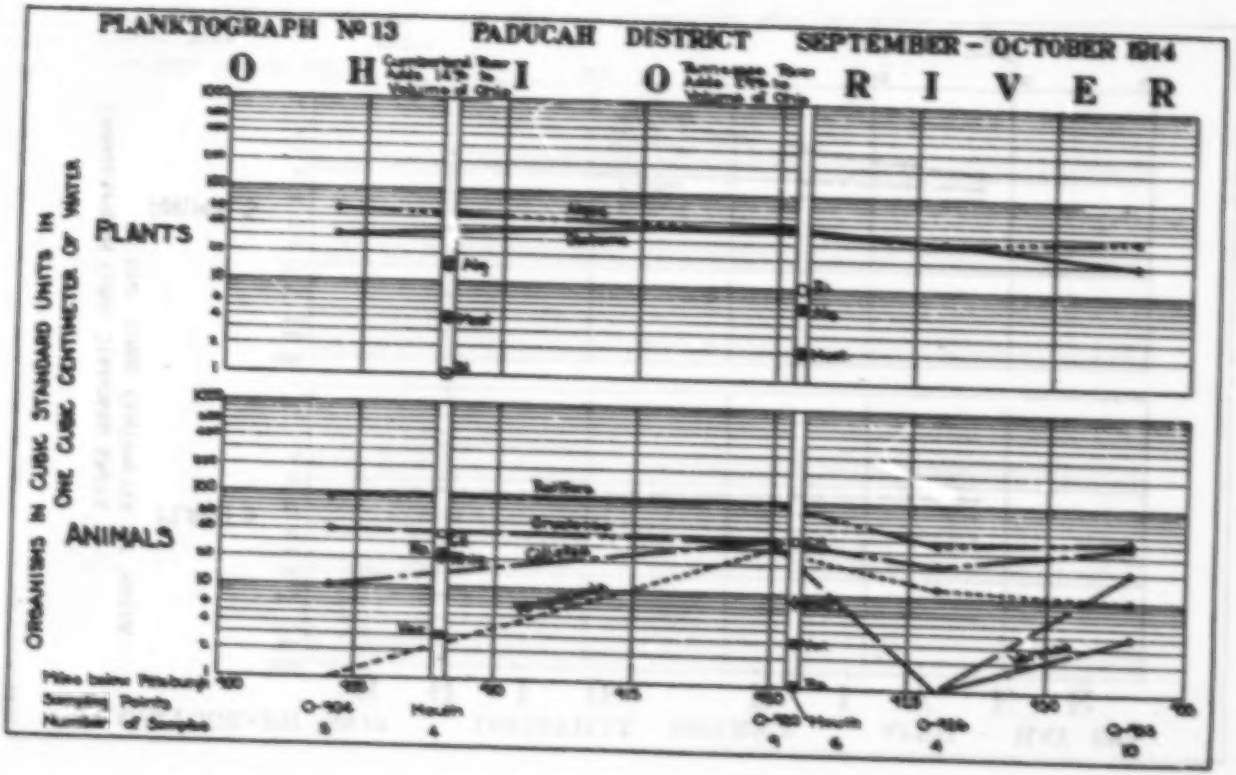

PLANKTOGRAPH Nº 8
CINCINNATI DISTRICT
JUNE – JULY 1915
OHIO RIVER
PLANTS
ANIMALS
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
Miles below Pittsburgh
Sampling Points
Number of Samples


PLANKTOGRAPH № 9 LOUISVILLE DISTRICT SEPTEMBER – OCTOBER 1914
O H I O R I V E R
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
PLANTS
ANIMALS
Diatoms
Desmids
Crustacea
Worms
Miles below Pittsburgh
Sampling Point
Number of Samples
600
605
610
615
620
O-598
17


PLANKTOGRAPH Nº 10 LOUISVILLE DISTRICT NOVEMBER 1964 – JANUARY 1965
O H I O R I V E R
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
PLANTS
ANIMALS
Miles below Pittsburgh
Sampling Points
Number of Samples
O-318
14
O-601
24


PLANKTOGRAPH №11 LOUISVILLE DISTRICT FEBRUARY – MARCH 1965
O H I O R I V E R
PLANTS
ANIMALS
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
Diatoms
Algae
Crustacea
Miles below Pittsburgh
Sampling Points
Number of Samples
600
605
610
615
620
625
O-598
9
O-629
18


PLANKTOGRAPH Nº12 LOUISVILLE DISTRICT APRIL – MAY 1915
O H I O R I V E R
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
PLANTS
ANIMALS
Diatoms
Rotifers
Ciliates
Miles below Pittsburgh
Sampling Points
Number of Samples
6
8


PLANKTOGRAPH № 13 PADUCAH DISTRICT SEPTEMBER – OCTOBER 1914
O H I O RIVER
PLANTS
ANIMALS
ORGANISMS IN CUBIC STANDARD UNITS IN ONE CUBIC CENTIMETER OF WATER
Miles below Pittsburgh
Sampling Points
Number of Samples
Mouth

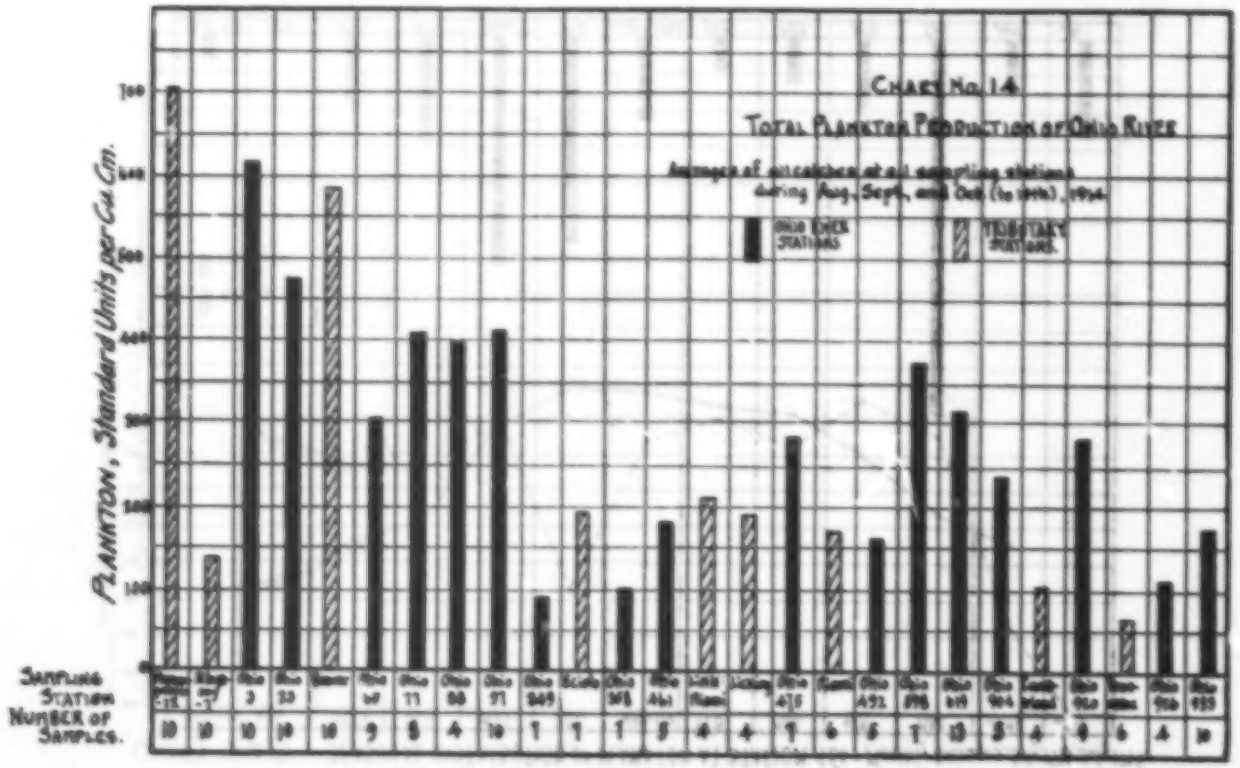
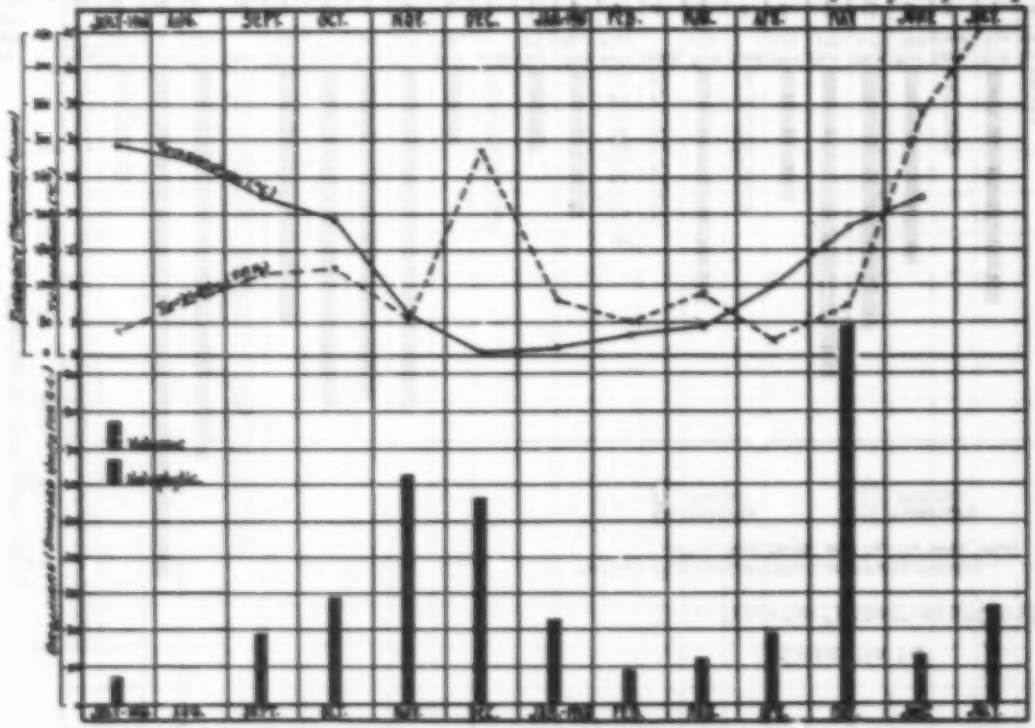


CHART No. 14
TOTAL PLANKTON PRODUCTION OF OHIO RIVER
Averages of all catches at all sampling stations during Aug., Sept., and Oct. (to 19th), 1924.
OHIO RIVER STATIONS
TRIBUTARY STATIONS
PLANKTON, Standard Units per Cu. Cm.
100
200
300
400
500
SAMPLING STATION
NUMBER OF SAMPLES.
10 10 10 10 10 9 8 4 10 1 1 1 5 4 4 7 6 6 7 13 8 4 8 6 4 10

CHART NO. 15 – SEASONAL DISTRIBUTION OF PLANKTON AT STATION 461 – Monthly Averages, July 1944–July 1945.



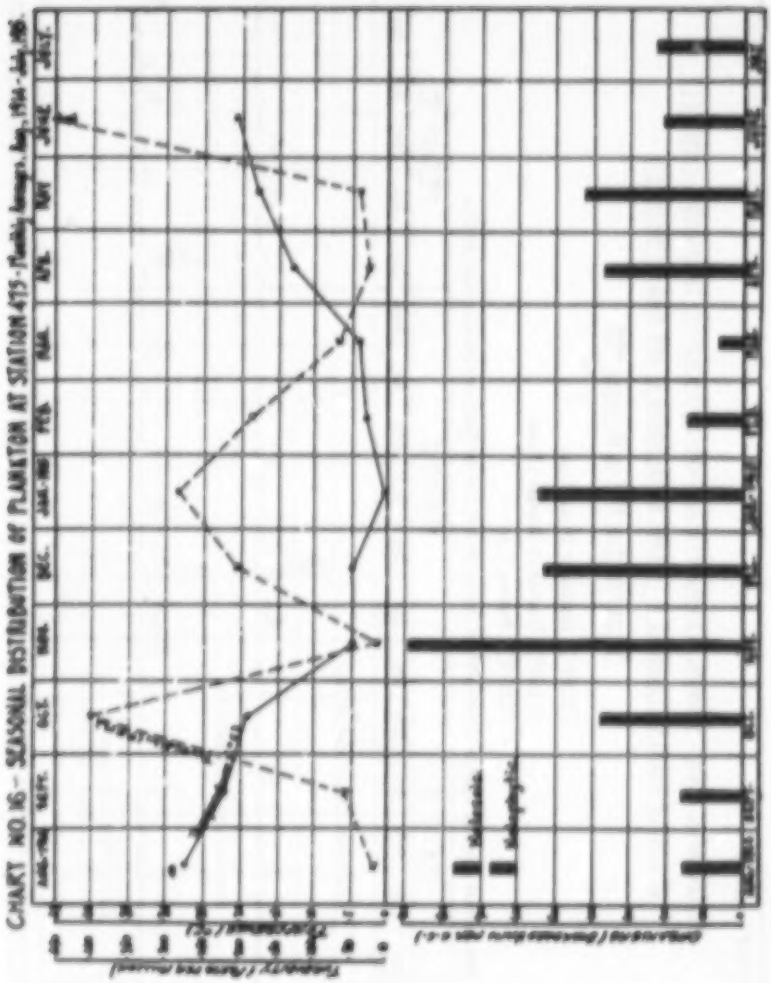


CHART NO. 17

HYDROGRAPHIC CURVES SHOWING SEASONAL FLUCTUATIONS IN DISCHARGE, THOUSAND SECOND FEET, OF LITTLE MIAMI AT PLAINVILLE, O., LICKING AT FALMOUTH, KY., AND OHIO AT CINCINNATI

PERIOD FROM JULY, 1914 TO DECEMBER, 1915.

PERIOD I: UNUSUALLY STABLE FLOW.
PERIOD II: UNUSUALLY UNSTABLE FLOW.
PERIOD III: NORMAL FLOW

Note: Vertical discharge scale for Little Miami and Licking amplified to ten times corresponding scale for Ohio

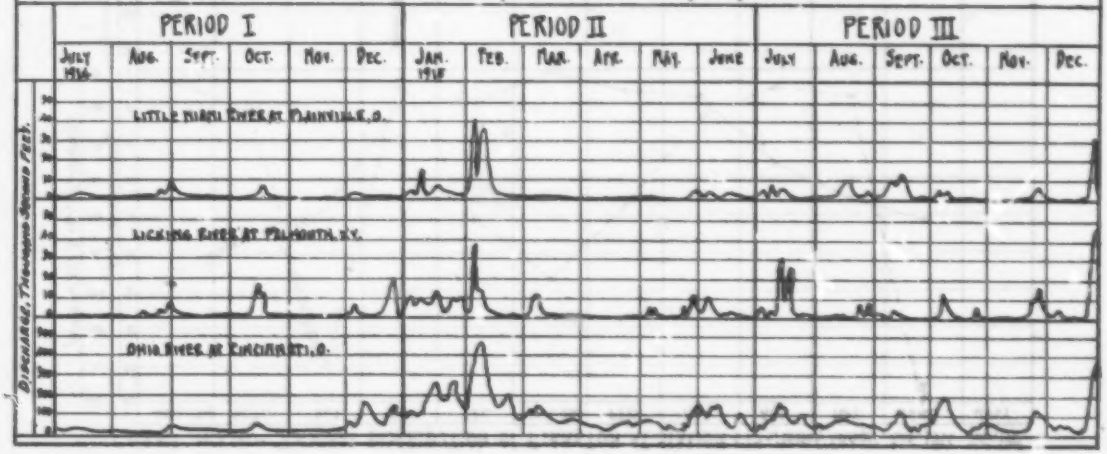
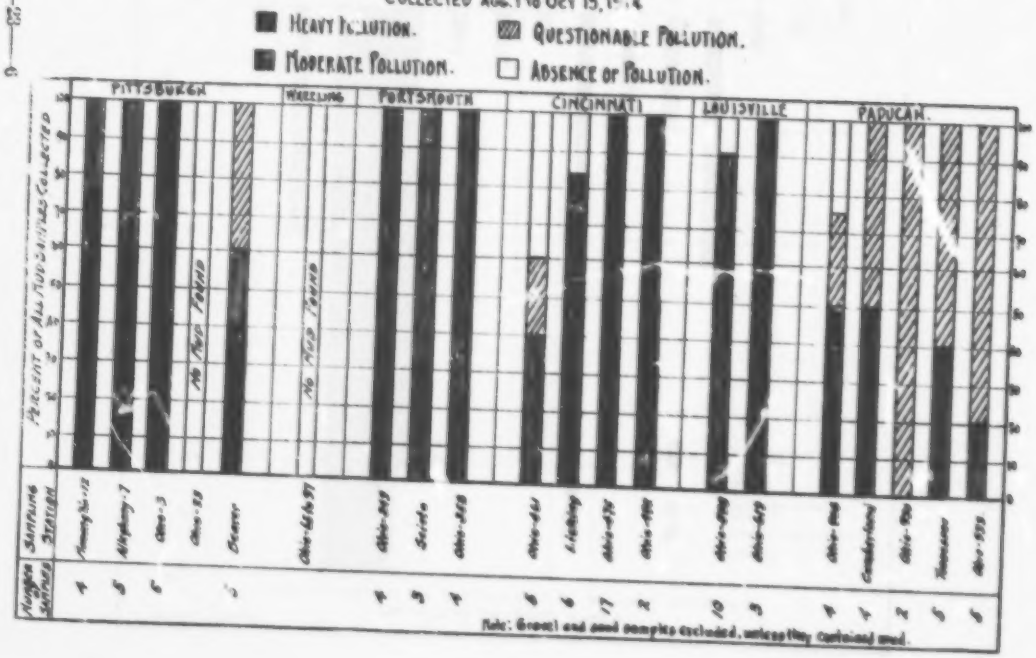


CHART NO. 18

SANITARY STATUS OF OHIO RIVER AS SHOWN BY THE PHYSICAL CONDITION AND THE ORGANISMS OF BOTTOM DEPOSITS.

COLLECTED AUG. 1 TO OCT 15, 1914


HEAVY POLLUTION.
QUESTIONABLE POLLUTION.
MODERATE POLLUTION.
ABSENCE OF POLLUTION.
PITTSBURGH
WHEELING
PORTSMOUTH
CINCINNATI
LOUISVILLE
PADUCAH.
PERCENT OF ALL ORGANISMS COLLECTED
No Red Found
No Red Found
Sanitary Station
Number of Species
Ohio-Mississippi
Tributaries
Ohio-Mississippi
Tributaries
Ohio-Mississippi
Tributaries

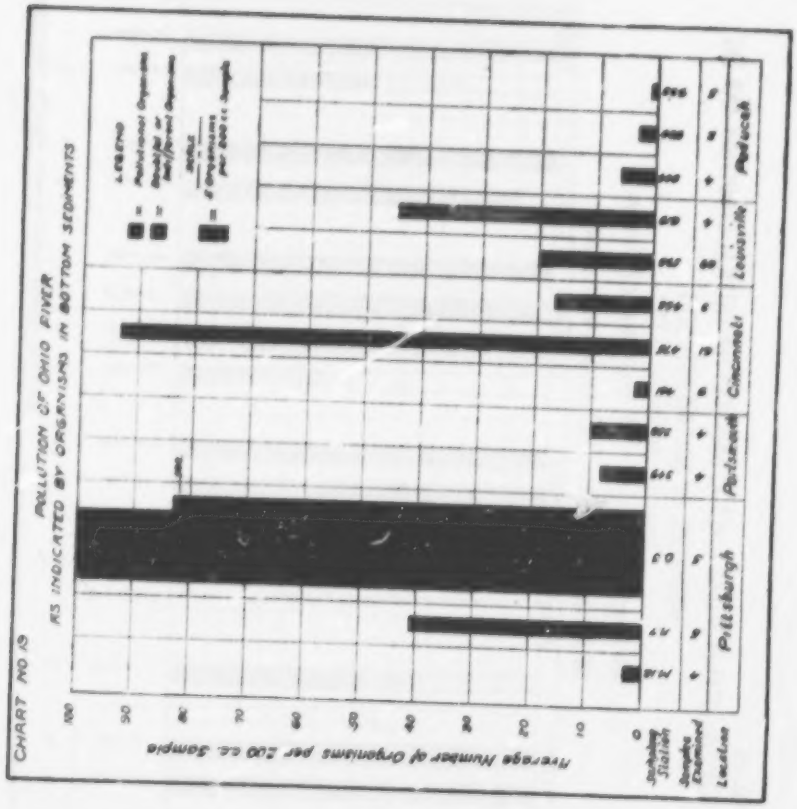
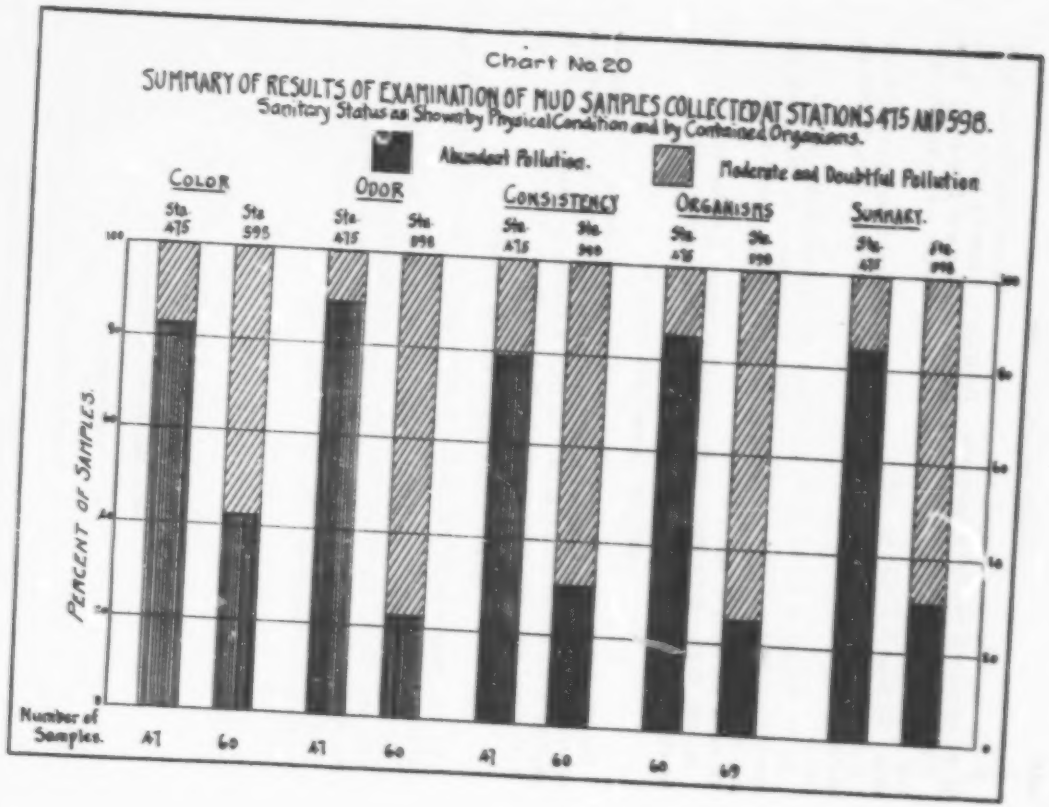


CHART NO. 13
POLLUTION OF OHIO RIVER
AS INDICATED BY ORGANISMS IN BOTTOM SEDIMENTS
LEGEND
Average Number of Organisms per 200 cc. Sample
Pittsburgh
Portsmouth
Cincinnati
Louisville
Paducah

Chart No. 20

SUMMARY OF RESULTS OF EXAMINATION OF MUD SAMPLES COLLECTED AT STATIONS 475 AND 598.

Sanitary Status as Shown by Physical Condition and by Contained Organisms.



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Available reprints and bulletins on stream pollution, issued by the Public Health Service, from which copies may be obtained without cost:

PUBLIC HEALTH BULLETIN.

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No. 86. Investigation of the pollution of certain tidal waters of New Jersey, New York, and Delaware, with special reference to bathing beaches and shellfish-bearing areas. By Hugh S. Cumming. 1917.

No. 87. Stream pollution. A digest of judicial decisions and a compilation of legislation relating to the subject. By Stanley D. Montgomery and Earle B. Phelps. 1917.

No. 97. Studies on the treatment and disposal of industrial wastes: I. The treatment and disposal of strawboard waste, by Harry B. Hommon. II. The determination of biochemical oxygen demand of industrial wastes and sewage, by Emory J. Theriault and Harry B. Hommon. 1918.

No. 100. Studies on the treatment and disposal of industrial wastes: III. The purification of tannery wastes, by Harry B. Hommon. (Final report.) 1919.

HYGIENIC LABORATORY BULLETIN.

No. 104. Investigation of the pollution and sanitary conditions of the Potomac watershed, with special reference to self-purification and the sanitary condition of shellfish in the lower Potomac River. By Hugh S. Cumming. Plankton studies by W. C. Purdy and hydrographic studies by Homer P. Ritter. 1916.

REPRINTS FROM PUBLIC HEALTH REPORTS.

No. 214. Studies on the self-purification of streams. By Earle B. Phelps. August 14, 1914.

No. 362. The sewage pollution of streams. By W. H. Frost. September 15, 1916.

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